ELECTRONIC VALVE TRAIN (EVT)

FOR 4-STROKE ENGINE

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by

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EXAMIANTION COMMITTEE

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ABSTRACT

The cam has been an integral part of the IC engine since its invention. The cam controls the breathing channels of the IC engines, that is, the valves through which the fuel air mixture (in SI engines) or air (in CI engines) is supplied and exhaust driven out. Recently due to demands for better fuel economy, more power, and less pollution, motor engineers around the world are pursuing a radical camless design that promises to deliver liberation from a constraint that has handcuffed performance since the birth of the internal-combustion engine more than a century ago. Electronic Valve Train (EVT) engine technology is soon to be a reality for commercial vehicles. In the EVT, the valve motion is controlled directly by a valve actuator. There's no camshaft or connecting mechanism.

"The future of Internal Combustion Engine is camless". We have decided to undertake the task to replace mechanically operated valves system of an IC engine by Electronic Valve Train (EVT). This project focuses to design an electronically controlled valve train to eliminate cam shaft, gear/belt drive mechanism, improve efficiency and reduce power losses in conventional design.

PREFACE

The Final Year Project is one of the most important stage and requirement in Bachelor of Mechanical Engineering. We got an opportunity to improve our practical knowledge during working on this project. This document is intended as the report to present as a detail account on the theoretical and practical work done.

In this report we have included various concepts, methodology, implementation, results and interpretation of our findings. We have tried our level best to explain each and every significant aspect of the FYP project comprehensively.

ACKNOWLEDGMENTS

Praise to Almighty Allah, who bestowed upon us the potential and ability to accomplish the goals of the Final Year Project. We are thankful to our parents, for their constant support and affection. We are grateful to Department of Mechanical Engineering and its members for supporting us in this project.

We wish to express deep sense of gratitude to our project supervisor, Dr. Mohsin Jamil, for his generous support and valuable guidance. We are really indebted to our members of guidance committee, Dr. Samiur Rahman Shah and Mr. Adnan Hanif, for their encouragement, support and help during the implementation of this project.

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ABBREVIATIONS

EVT	Electronic Valve Train
VVT	Variable Valve Timing
TDC	Top Dead Center
BDC	Bottom Dead Center
EVO	Exhaust Valve Opening
IVO	Intake Valve Opening
EVC	Exhaust Valve Closing
IVC	Intake Valve Closing
ECU	Electronic Control Unit
OHC	Over-head Cam
IVL	Intake Valve Lift
EVL	Exhaust Valve Lift

NOMENCLATURE

N	No. of revolutions
F	Force (N)
f	Frequency (Hz)
S	Valve lift (mm)
r	Radius (mm)
ʀ	Gear ratio
τ	Torque
w	Rpm
P	Power

CHAPTER 1

1 INTRODUCTION

The cam has been an integral part of the IC engine since its invention. Recently due to demands for better fuel economy, more power, and less pollution, motor engineers around the world are pursuing a radical camless design. Project aims to replace mechanically operated camshaft-valves system by electronic operation in a reciprocating internal combustion engine. Electronic Valve Actuation is a new improved technology in which mechanical linkages such as rocker arm, camshaft and gears are removed and replaced by electro-mechanical actuators to actuate the valves [1]. Push solenoids are selected after considering several alternatives for actuating the engine's valves because they provided simplicity of design which is an important consideration for the project.

Force to be produced by solenoid for push/pull stroke depends on three factors; Pressure on valve head, valve spring compression and acceleration component. Spring constant for the solenoid is calculated by measuring the deflection against the forces applied on the spring and then the solenoid was selected against that spring constant. The cam profile shows the different angles of the rise/dwell/fall which are used for opening and closing valves. This timing of valve opening and closing can be controlled by comprehensive control system comprising of microcontroller, proximity laser sensors and solenoids. This will enable to implement the Electronic Valve Timing (EVT).

1.1 Project Scope

Aim: To replace mechanically operated camshaft-valves system by electronic operation in a reciprocating internal combustion engine.

Objective: This project specifically intends to design an electronically driven and controlled valve mechanism to:

- Eliminate gear, pulley and shaft mechanism
- Drive valve mechanism electronically
- Implement microcontroller in valve timing

1.2 Application

The engines powering today's vehicles, whether these burn gasoline or diesel fuel, rely on a system of valves to admit fuel and air to the cylinders and let exhaust gases escape after combustion. Rotating steel camshafts with precision-machined egg-shaped lobes, or cams, are the hard-tooled brains of the system. They push open the valves at the proper time and guide their closure, typically through an arrangement of pushrods, rocker arms, and other hardware. Stiff springs return the valves to their closed position. In an overhead camshaft engine, a chain or belt driven by the crankshaft turns one or two camshafts located on top of the cylinder head. A single overhead camshaft design uses one camshaft to move rockers that open both inlet and exhaust valves. The double overhead camshaft, or twin-cam, setup devotes one camshaft to the inlet valves and the other to the exhaust valves.

Advantages and Possibilities

EVT have the advantages that could be seen:

- Engine becomes mechanically simple; no timing gears, camshaft and push rods. Electronics that replace these mechanical parts are lighter and smaller.
- Mechanical losses are reduced because there are fewer moving parts. Electrical energy required to operate the valves can be supplied by on-board battery.
- An EVT engine can be throttled by changing the valve timing. An "Electronic Throttle" that reduces the intake charge by valve timing has lower pumping losses than does an engine throttled by the traditional method of a restriction in the intake manifold.

1.3 Project Management

For smooth and timely implementation, project was divided into various sections and estimated days were allotted to each.

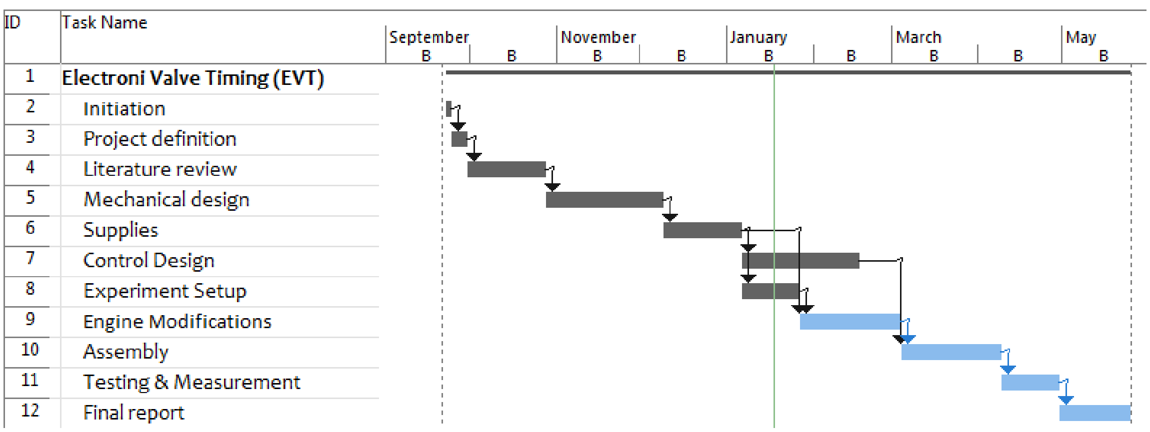

Figure 1: Gantt chart

CHAPTER 2

2 LITERATURE REVIEW

Idea of a camless IC engine had its origins as early as 1899, when designs of Variable Valve Timing (VVT) surfaced. It was suggested that independent control of valve actuation could result in increased engine power. The first camless engine was built in 1999. Siemens VDO Automotive, in partnership with BMW, built a prototype electronic valve train engine. In place of cams it used solenoids, electromagnetically controlled plungers, which were already widely used in cars for things like electronic door locks. The prototype engine was installed in a 3-series BMW sedan. It worked, but had several significant shortcomings. BMW's work proves that it is feasible to control the exhaust valves of an engine using electromagnets [2].

2.1 Background and the Related Art

Present invention relates to variable valve operating for internal combustion engines and more particularly, to constructions and methods that can be easily incorporated into the standard internal combustion engines introducing automatic electronic controlled valve timing which is variable for each increment of engine conditions, that is, as the engine load increases or decreases during operation. As a result, the optimum valve timing may be provided for each operating state, which in turn, improves volumetric efficiency and combustion efficiency.

It has been recognized that when the internal combustion engine is, for instance, starting or in operation at a low speed, the combustion efficiency within a combustion chamber is improved if supplying a relatively small amount of an air-fuel mixture into the combustion chamber to produce an eddy flow. It is a significant factor that controls the performance of a spark ignited, internal combustion engine which is implemented by the valve timing mechanism.

For an internal combustion engine operating speeds are rapidly changing over a substantially wide range and does not remain at single speed level, such as the engine of a modern bike or car. Similarly, it has been long realized by engine specialists that in high performance engines, control of valve timing will give optimized engine operation results. The efficient timing of intake and exhaust valves at starting or idle conditions; at normal load range and at high performance requirement is relatively different.

Over the operating range the efficient valve timing for an engine is varying, mainly depending upon the speed and load, and it is necessary to adjust the timing to match a particular operating condition. But production engines have fixed valve timing arrangement generally designed to provide optimized valve timing for a particular range. In conventional engines as the valves are controlled by cams, valve timing is a bias towards the normal load conditions against the idle and the high performance output. Alternatively in engines where high performance is required the timing is adjusted to maximize engine output and is a following efficient timing for the idle and normal load conditions.

In order to improve the efficiency over a wider range of engine speed and load states, it has been proposed to introduce a variable valve timing mechanism to replace the camshafts in the drive train. In this manner, the timing schedule of the intake and exhaust valves can be adjusted so as to provide maximized performance for a larger operating range.

The variable valve timing mechanisms which have been proposed generally fall into two categories. With the first of these and the simpler arrangement, for example the US patent no. US4261307 entitled "Variable valve timing control for internal combustion engines", the timing of both camshafts is generally altered in the same direction and at the same degree. This is done, for example the US patent no. US 6250266 B1 entitled "Variable valve timing mechanism for engine", by interposing one variable valve timing mechanism in the timing drive between the engine output shaft and the camshafts. This has the advantages of simplicity, lower cost and still provides greater flexibility in engine performance.

The other type of mechanism includes, a pair of valve timing mechanisms each of which is interposed between the valves drive and engine output shaft that can replace the camshafts of the engine and replicate it in terms of its functions. This, including the control mechanism, which also offers the possibility of a greater flexibility in overall engine performance.

2.2 Design Concept

Considering the above-mentioned short comings of conventional spark ignited internal combustion engines, present invention provides an electronic valve control mechanism arranged to vary the opening and closing of the inlet and exhaust valves when the engine is running at different load conditions, for instance allowing a smaller portion of the fuel-air charge to enter the combustion chamber and avoiding a reasonable pumping loss of energy which is unnecessary at partial load.

Alternate to conventional engine design, it is an object of this invention to provide a valve operating system designed to drive the opening and closing of the intake and exhaust valves by an electromagnetic force.

Accordingly, in this invention, there is provided an electronic valve train for an internal combustion engine, comprising: intake and exhaust valves capable of opening and closing intake and exhaust valve bores which are provided in a cylinder head to lead into a combustion chamber.

Accomplishing another object of invention, each of the intake and exhaust electromagnetic drive comprises an electromagnet connected to corresponding one of the valves, a valve-opening electromagnet capable of providing a force for pushing its plunger to open the intake valve, a valve-closing return spring for pulling its plunger in a direction to close the intake valve. Thus, the present invention can be applied to a valve operating system of a type which is designed to drive the intake and exhaust valve in an ON-OFF states by means of an electronic driver between an opened position and a closed position.

The embodiments of this invention are adapted in a production single cylinder internal combustion engine. This engine comprises an output shaft that is connected with crankshaft and is driven by combustion occurring in combustion chamber. Intake and exhaust timing is controlled by electronic driver provided for incorporating the control system synchronized with speed of the output shaft. A controlled valve timing mechanism is provided that can be adapted to provide variable timing for both valves adjusting with the operating conditions simultaneously. The duration and schedule of timing of intake and exhaust valve opening and closing is controlled by the control system.

Thus, although the illustrated embodiments show an arrangement wherein the intake and exhaust valves of single cylinder four stroke engine are operated, the invention also may be practiced with four or six cylinder engines. The structure for achieving this should be readily apparent from the description of the preferred embodiments which are explained.

The above and other objects, features and advantages of the invention are detailed below, in relation with the accompanying drawings.

2.3 Conventional Engine

Since the timing of the engine is dependent on the shape of the cam lobes and the rotational velocity of the camshaft, engineers must make decisions early in the automobile development process that affect the engine’s performance. The resulting design represents a compromise between fuel efficiency and engine power. Since maximum efficiency and maximum power require unique timing characteristics, the cam design must compromise between the two extremes [3].

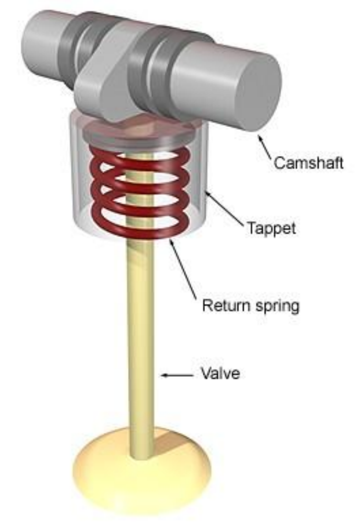

Figure 2: Simple cam valve arrangement [4]

Drawbacks

Drawbacks of camshaft are as under:

- It consumes power of the engine
- Size of the engine is increased
- Weight of the engine is increased
- Friction between the mechanical parts
- Complicated design

2.4 Variable Valve Timing Camshaft

As a camshaft normally has only lobe per valve, the valve displacement and lift is fixed. The camshaft runs at half the crank speed. Although many modern engines adjust the lift and valve displacement in a working engine but it is difficult. Some manufacturers use systems with more than one cam lobe (Honda VTEC, Toyota dual-VVTi), but this is still a compromise as only a few profile can be in operation at once [4]. This is not the case with an electronic valve train engine, where lift and valve timing can be adjusted freely from valve to valve and from cycle to cycle switching off the cylinder entirely [5].

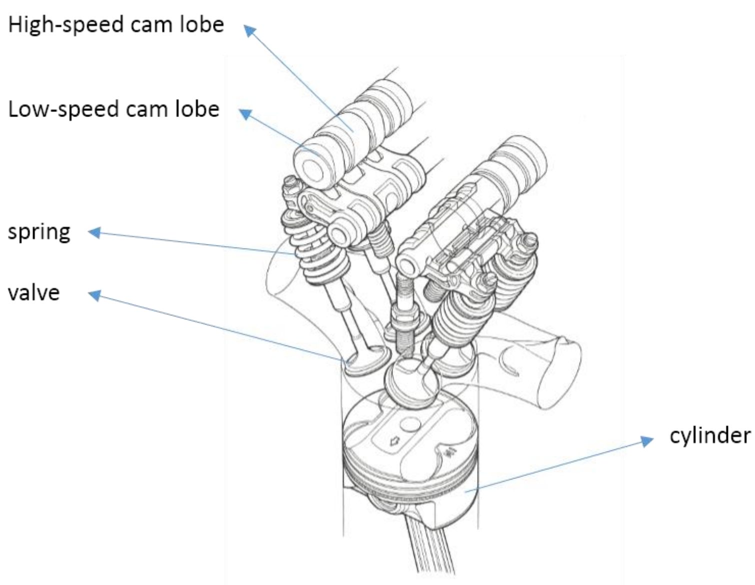

Figure 3: Variable valve timing camshaft [7]

2.5 Variable Valve Timing Significance

Significance of various parameters for variable valve timing are discussed below:

Exhaust Valve Opening Timing (EVO): In order to extract the maximum amount of work (hence efficiency) from the expansion of the gas in the cylinder, it would be desirable not to open the exhaust valve before the piston reaches Bottom Dead Centre (BDC).

Exhaust Valve Closing Timing (EVC): This requires EVC to be at, or shortly after TDC. In engines where the exhaust system is fairly active (i.e. Pressure waves are generated by exhaust gas flow from the different cylinders), the timing of EVC influences whether pressure waves in the exhaust are acting to draw gas out of the cylinder or push gas back into the cylinder [6].

Intake Valve Opening Timing (IVO): Opening the intake valve before TDC can result in exhaust gasses flowing into the intake manifold instead of leaving the cylinder through the exhaust valve. The resulting EGR will be detrimental to full load performance as it takes up space that could otherwise be taken by fresh charge.

Intake Valve Closing Timing (IVC): For maximum torque, the intake valve should close at the point where the greatest mass of fresh air/fuel mixture can be trapped in the cylinder.

Peak Valve Lift: The chosen value of peak valve lift is a compromise between low speed and high speed full load requirements [7].

2.6 Electronic Valve Actuation

Electronic Valve Actuation is a new improved technology in which mechanical linkages such as rocker arm, camshaft and gears are removed and replaced by electro-mechanical actuators to actuate the valves [8]. Actuators are coupled with inlet and exhaust valves of the engine, and these inlet and exhaust valves are opened and closed at an appropriate timing using a control system [9].

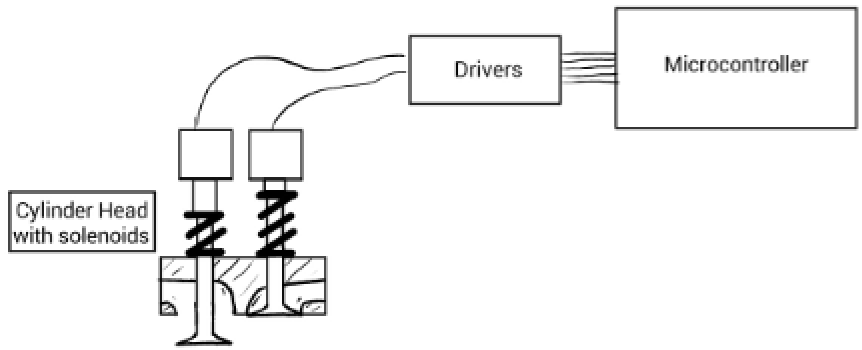

Figure 4: Electronic valve actuation [12]

CHAPTER 3

3 METHODOLOGY

3.1 Electronic Valve Train (EVT)

Electromagnetic solenoids were selected after considering several alternatives for actuating the engine's valves because they provided simplicity of design which is an important consideration for the project. Main components of EVT are: electromagnetic solenoids, controller and proximity sensors.

To eliminate the camshaft, rocker arm and other connected mechanisms, the EV engine makes use of three vital components sensors, microprocessor control unit and actuators.

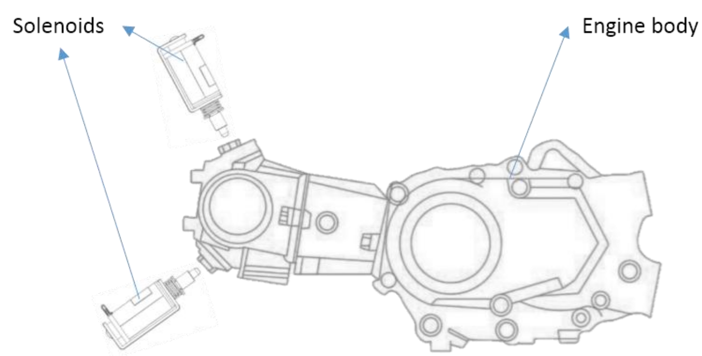

Figure 5: Engine modification concept

Proximity sensors will send signals to the electronic control unit (ECU). The ECU consists of a microprocessor, the microprocessor issues signals which in turn controls the actuator, to function according to the instructions.

3.2 Engine

Selection of engine is the first important step to start the project. Honda CD-70 OHC 3.5 HP engine is chosen to demonstrate the Electronic Valve Train project. The following points are considered while selecting an engine:

- OHC single cylinder – Compact
- 4-stroke engine - uses valve arrangement
- Economical choice
- Easily available spare parts

Table 1: Engine specifications

Engine Specifications	
Engine Type	4-stroke OHC single cylinder air cooled
Displacement volume	72 cm3
Bore & Stroke	47 x 41.4 mm
Compression Ratio	8.8 : 1
Valve head radius	10 mm

3.3 Valve Spring Force

Spring constant for the solenoid is calculated by measuring the deflection against the forces applied on the spring using the Universal Testing Machine (UTM) and then the solenoid was selected against that spring constant.

Figure 6: Valve spring testing on Universal Testing Machine (UTM)

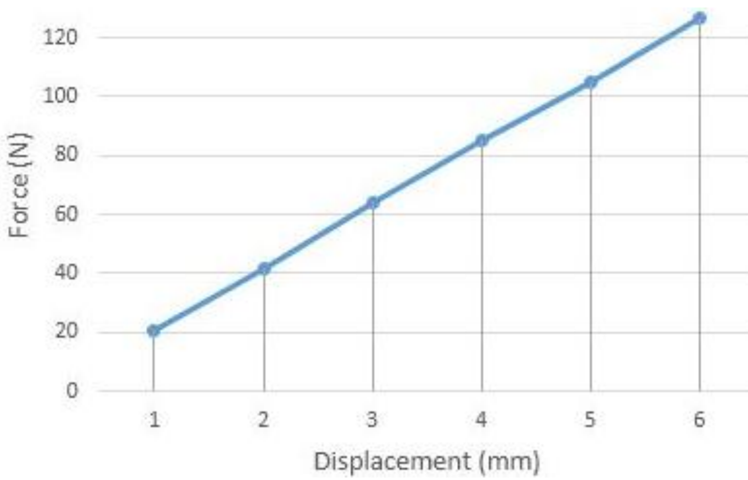

Figure 7: Valve spring behavior

3.4 Solenoid

Woodward solenoid 1750 Push series was selected to drive the valve mechanism for our project.

Calculating Parameters

Force acting due to pressure inside cylinder is maximum for exhaust valve opening and lesser during intake valve opening.

Therefore force acting on the critical valve head (exhaust) can be calculated as follows:

F = force VH + spring force + acceleration force
= (πr^2 x pressure) + (constant x S) + (0.2 x spring force)
= [π(0.01)^2 x (0.2 x 10^6)] + (21.06 x 5) + (0.2 x 21.06 x 5)
= 62.831 + 105.3 + 21.06
= 189.19 N

f = max. N / (60 x 2)
= 2000 / (60 x 2)
= 16.67 Hz

Note:

EV pressure: 0.1 to 0.2 MPa

EV outer radius: 10 mm

Valve lift: 0 to 5 mm

20% of spring force is enough to provide acceleration

Rpm range: 800 to 2000 rpm

Table 2: Solenoid specifications

Model	Woodward 1750
Type	Push
Operating force	236 N
Stroke	25 mm
Duty cycle	Continuous duty

Temp range	(-40˚C to +121˚C)
Weight	0.7 kg
Features	Dual Coil design, protective boot, return spring

3.5 Control System

Control system designed for the electronic valve arrangement consists of laser/proximity sensors, microcontroller and solenoid actuators, designed in a closed loop control system for the project in which no feedback is involved.

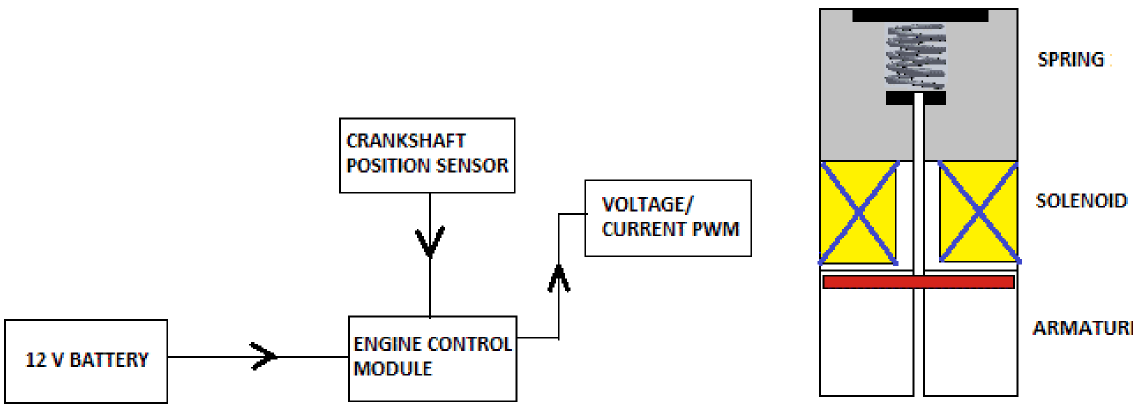

Figure 8: Design of control system [13]

Block Diagram

Sensors act as an input in control system of the electronic valve arrangement; it sends the input signal to the ECU that includes microcontroller which after processing the signal sends a pulse to the actuating mechanism.

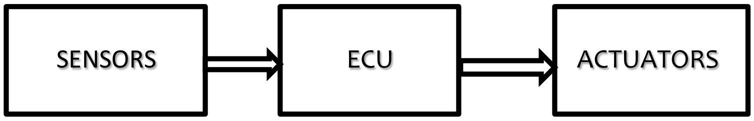

Figure 9: Overview of control system

3.5.1 Control Components

Sensors

Proximity sensors used to observe the position of Fly wheel which in turn gives timing of opening and closing of valves through the solenoids controlled by the ECU program.

Figure 10: Laser proximity sensor

Microprocessor

Arduino uno R3 based on microcontroller ATmega328 is to be used as the ECU. The microprocessor unit is selected on following criteria:

- Code could be re-written and stored easily.
- Provide sufficient processing power to run the program promptly without any delay.

Figure 11: Arduino uno R3

3.6 Cam Profiling

Took the cam of engine and drew the cam profile by using the dial gauges with protector. This profile shows the different angles of the cams for opening and closing the valve.

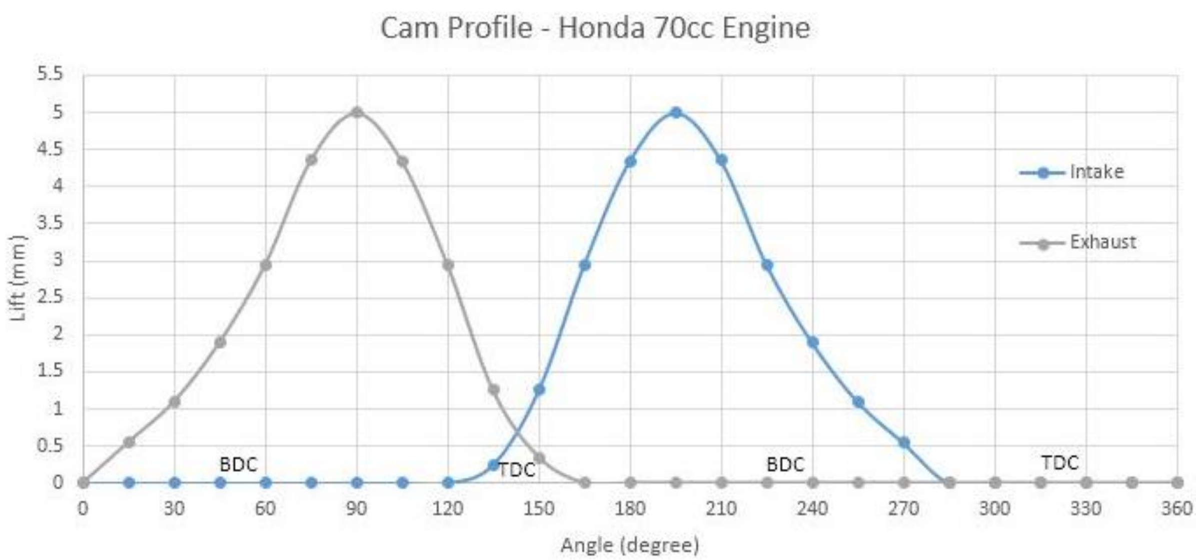

Figure 12: Cam Profile

Method used for cam profiling:

First taking off the head casing of the engine in order to expose the cam assembly, top dead center marking on the fly wheel with the TDC marking was adjusted and patched the degree wheel on the fly wheel. Doing this also confirmed the TDC, BDC, rise, fall and dwell of the valve timing given by the manufacturer by rotating the fly wheel.

To remain accurate, fastened the assembly in order to attach the dial gauge firmly in the desired position so the tip of the dial gauge rests on the cam surface. Then set the pointer on the dial gauge to its zero position after placing the tip on the cam where it provides no lift to the valve. Rotating the fly wheel in the counter clockwise direction, take reading of the valve lift provided by the cam profile after equal intervals. Finally drew the cam profile using graphing options available in Microsoft excel.

Same procedure was repeated for both the inlet and the exhaust cams and downsized the reading interval to make an acceptable cam profile that clearly shows the desired angles.

3.7 Modification

3.7.1 Removal of Cam Shat

Head of the engine was dissembled from the engine so that cam could be removed.

Figure 13: Engine Head without Camshaft mechanism

3.7.2 Installation of Solenoid

A DC-type solenoid was made to implement the proposed system. Also a disc assembly was designed in accordance with the threads available on the valve's passage so that the actuators sit firmly and at the right angle to provide optimum lift to the respective valve.

The solenoids used are capable of the following:

- Generating enough force to open the valve
- Providing enough force to hold the valve open

3.7.3 Adjustment of Intake and Exhaust Valves

Intake and exhaust valves are adjusted in such a way that they open and close by the help of solenoid. The adjustment of solenoid actuators on valve sleeves was also compulsory so that no wear and tear occurred during engine operation.

3.7.4 Crankshaft sensor

A wooden encoder for the sensor was made and mounted on the flywheel of engine in order to feed the crankshaft's position information to the metal proximity sensor. It helped in implementing exact valve timing, keeping in mind the limitations of sensors operating frequency and simplicity of programming.

The metal strips were placed on wooden extension of flywheel in accordance with the intake and exhaust valves operation duration measured earlier experimentally. The opening and closing angles were used as measured on the cam profile. Sensors are proximity sensors used to sense the metal strip for opening and closing of valves used as a solenoid valves via the control unit.

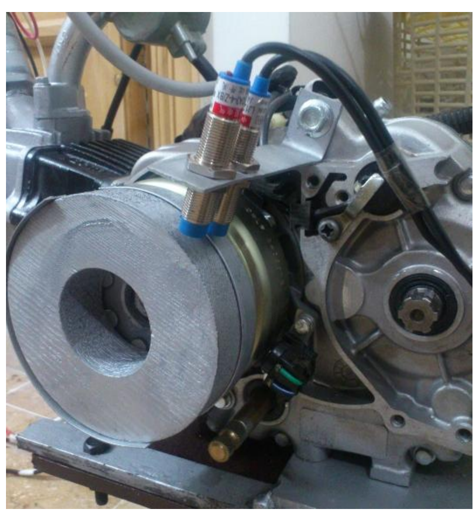

Figure 14: Crankshaft position sensor

3.7.5 Programming

Programing constituted an essential part of the project. It had to be simple enough to allow for customization, yet be efficient enough for high frequency operation of the actuated valves.

3.7.6 Proteus Simulation

After making the design of the electronic valve arrangement control system, Simulation was done in Proteus combined with microcontroller design in Arduino.

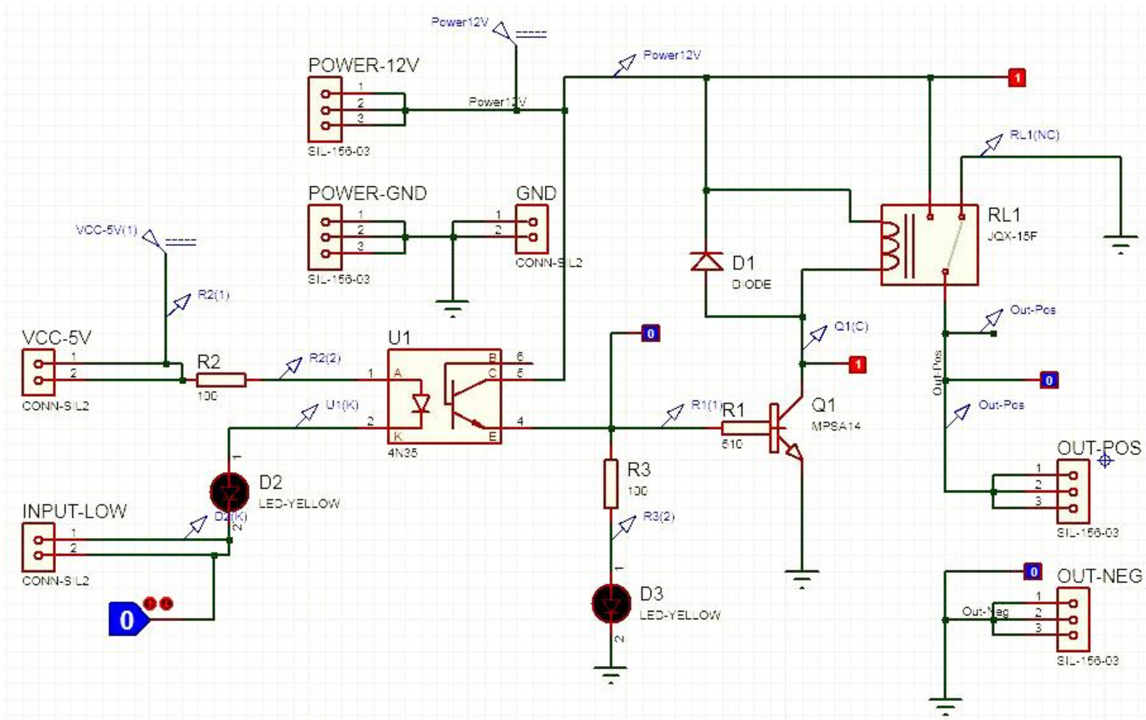

Figure 15: Circuit schematic: Relay switching for electromagnets

3.8 Integration of hardware and software

The hardware entities and software packages was finally integrated with links to each other. The EVT mechanism comprises now of the control system with its components like microcontroller, position sensor; electromagnets; drive circuits; modified engine head and auxiliary parts. All the sub-systems were adjusted according to their alignment and functional role.

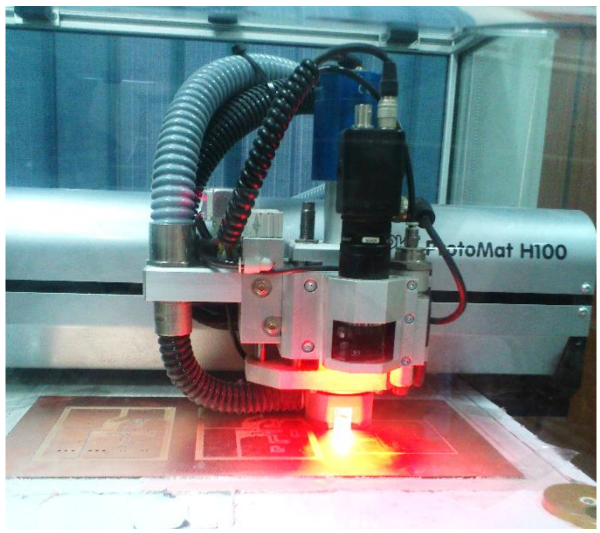

Figure 16: Fabricating control circuit

CHAPTER 4

4 RESULTS

4.1 Mechanical Design

The proposed mechanical design has reduced the required parts of the mechanical system. Camshaft, rocker arm, timing chain, tappet rod and other mechanical components were removed by the use of solenoid as direct actuator of the valves. As mentioned earlier, the force for the solenoids to drive the valve easily and safely was calculated by measuring the spring constant for the existing spring in the Cylinder head of the engine. The cap for the intake and exhaust sides were removed and a mounting was designed to firmly attach the solenoid to the engine head while keeping in mind that the plunger of the solenoid is parallel to the stem of the valve and centers of both are perfectly joined. The solenoid thus drives the valve of the engine directly.

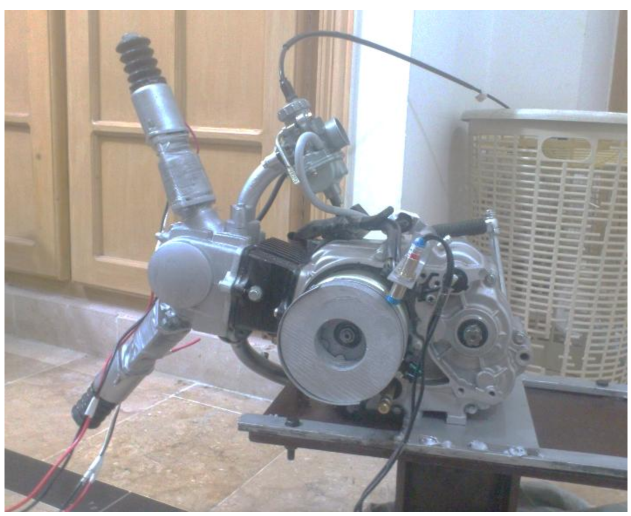

Figure 17: Complete EVT mechanism assembly

4.2 Software Performance

The system was integrated together with the software and made to work coherently. Each segment was tested individually and found functional. There are working code modules for the Solenoid driver Circuit, reading the position encoder and altering the Solenoid driver Circuit. These software modules are working together and are completely flexible to easily adapt to any other model of the system.

4.3 Performance Curve Comparison

Gear ratio = ʀ = 1.3

τ = T_out = (T_in)(ʀ)

P = τ w

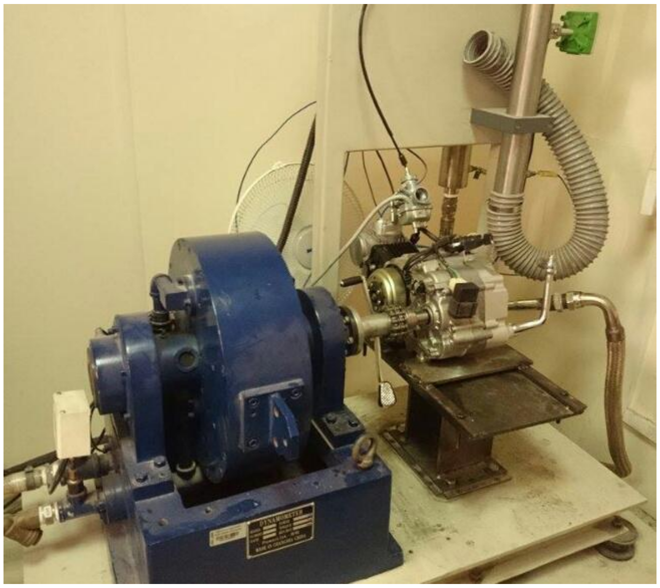

Figure 18: Engine testing on Dynamometer

4.3.1 Engine Dynamometer Testing

The graph shows the final results of power with EVT engine. These graph values taken from the engine test bed during practical.

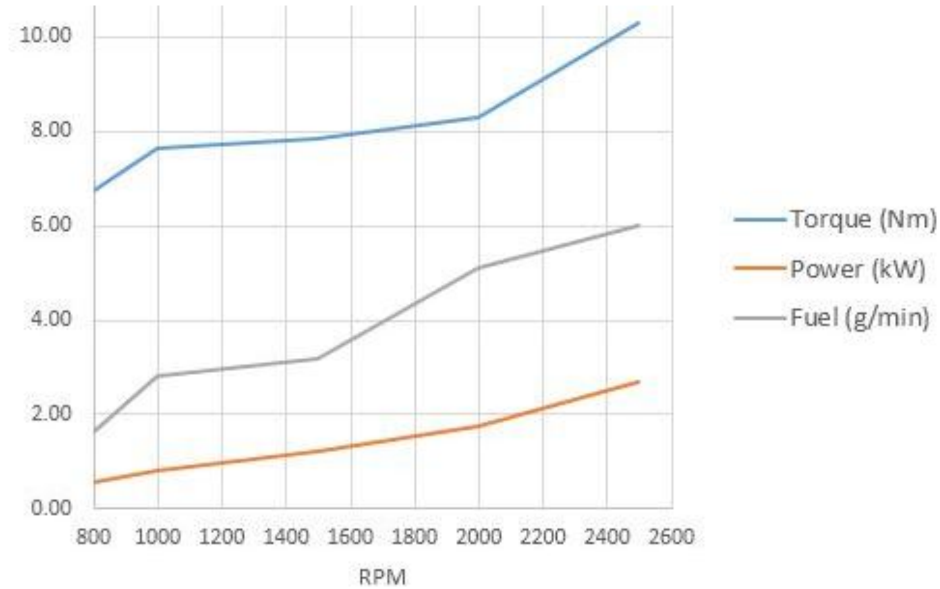

Figure 19: Engine dynamometer test results

4.3.2 Comparison with the Reference

The graph shows the final results of torque and power at different speed. The values are taken from the test bed during practical and comparison is made with software (Engine Analyzer) simulation of engine. The comparison shows that the power output is decreased whereas by increasing the speed of the engine torque is improved by increasing speed.

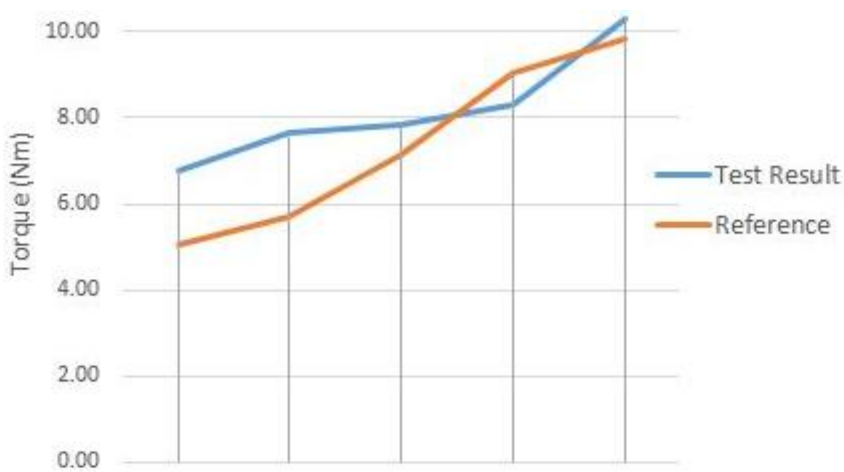

Figure 20: Torque comparison

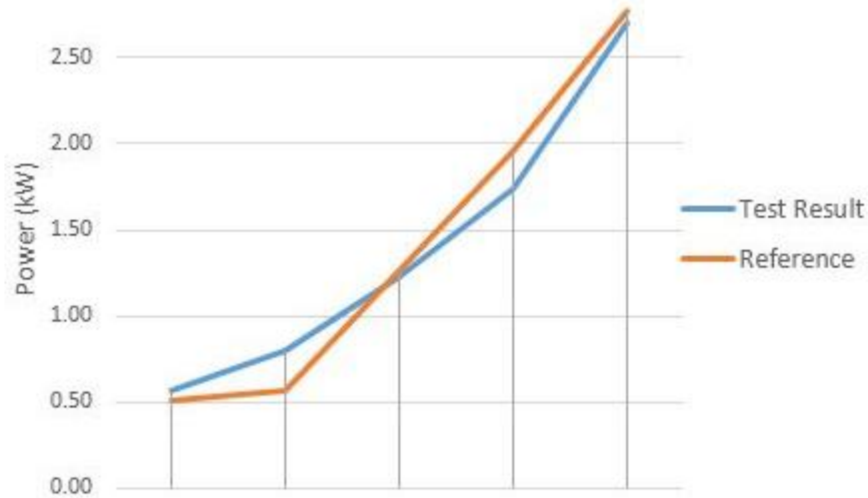

Figure 21: Power comparison

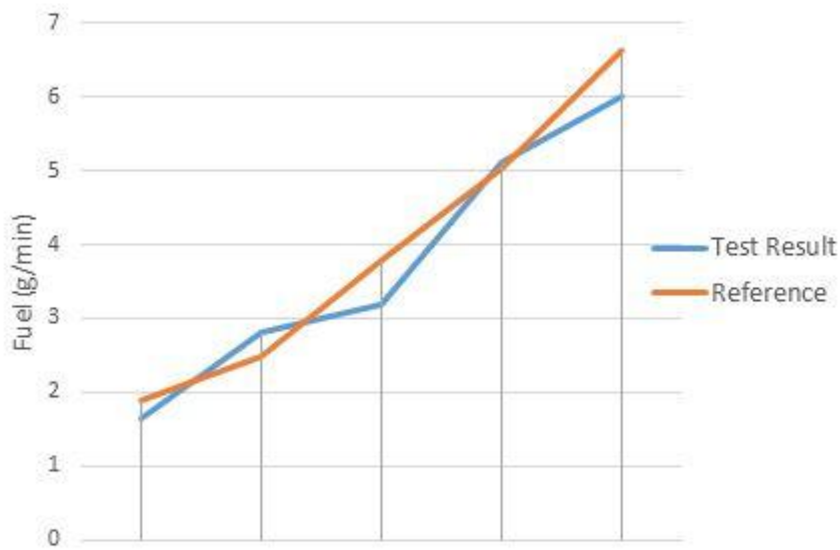

Figure 22: Fuel consumption comparison

The final result of fuel consumption of engine test and reference are plotted in the above graph.

4.3.3 Control Circuit

The relay switching circuit to accompany micro controller designed as driver to the solenoids functioned fully meeting all the frequency and logic requirements.

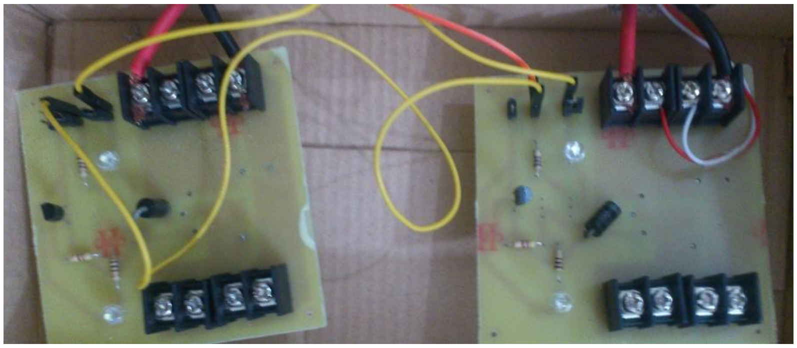

Figure 23: Driver relay circuit

CHAPTER 5

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Solenoid operated valves is capable of providing very flexible variable valve timing rather possibly infinitely variable valve timing. With the proper control hardware and software the engine designer should be able to implement optimum valve timing for any desired set of engine operating conditions.

We are satisfied with overall performance, quality and progress of the project.

5.2 Restrictions

As an opinion following are the limitations which are holding back EVT technology:

- The variable valve lift mechanism, which can function with respect to engine operating conditions, is not reliable.
- Always soft landing the valve on the valve seat is challenging even with a valve position sensor.
- Solenoid operated valves create audible and objectionable noise rising from vibrations and its inherent design.

5.3 Outcomes of the Project

Solenoid operated valves is capable of providing very flexible variable valve timing rather infinitely variable valve timing. With the proper control hardware and software the engine designer should be able to implement optimum valve timing for any desired set of engine operating conditions.

With solenoids it is possible to change the valve timing and duration. The software can determine the crankshaft position and apply voltage to the solenoid to open the valve at the desired time. The voltage can be removed from the solenoid such that it closes at the desired time.

5.4 Benefit to the students involved

- The key skills that were learned during the completion of project are:
- A detailed knowledge of internal combustion engines.
- System design skills to calculate forces, selection of components such as solenoid and define the control system.
- Mechanical design skills to modify the head and design the parts to mount the solenoids.
- Machine shop skills to do the fabrication and use of special materials in manufacturing.
- Electrical software and hardware skills to design, code and assemble the micro computer controls.

5.5 Future Work

- Apply this prototype on bigger cylinder engines for optimum performance in terms of parameter’s discussed in this study.
- This prototype can be further refined by utilizing compact and efficient actuators which also decreases vibrations in the engine as well as increases fuel efficiency.
- Designing of special engine heads for actuators, can be done which reduces the need of designing a special assembly for mounting electronic actuators on the engine head.

- The size of the fly wheel attachment can be reduced by designing a control system that would directly relate the size of fly wheel with the valve events required for the engine.
- Variation in terms of variable valve lift would also be achievable.
- Vibration analysis should be incorporated in the design process.
- By designing the control process in such a way that it is integrated with an inbuilt test which would most efficiently avoid a valve event being missed.
- A control system is proposed which would be able to disconnect the crank circuit if there is a fault in our valve actuation mechanism.
- The use of a more reliable sensing system is proposed as done in the project the use of metal strips that define the valve opening and closing durations in an effective way.
- RPM sensor can be integrated in the control system that would act as a secondary measure and would actuate the valve by predicting valve events preprogrammed in the logic design.

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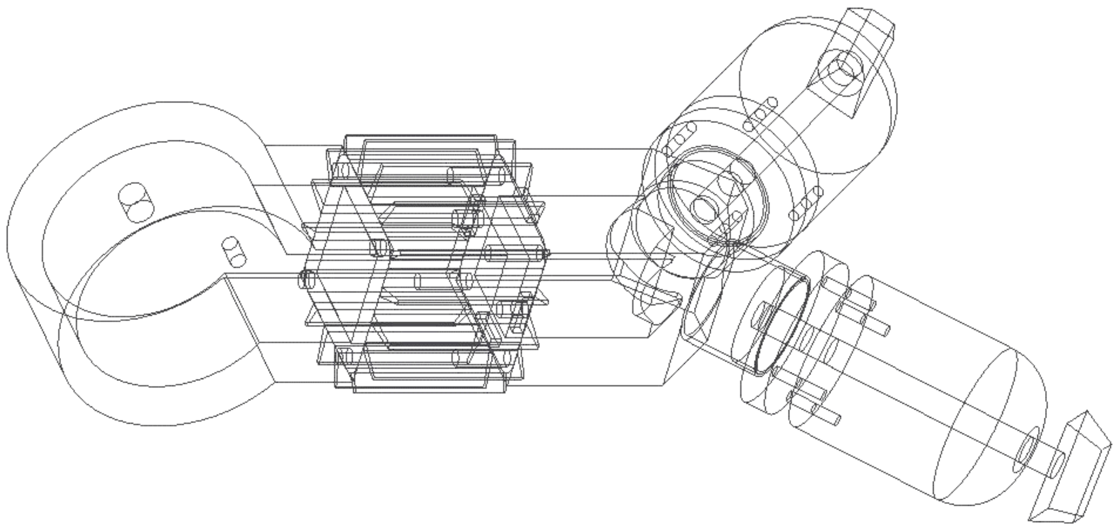
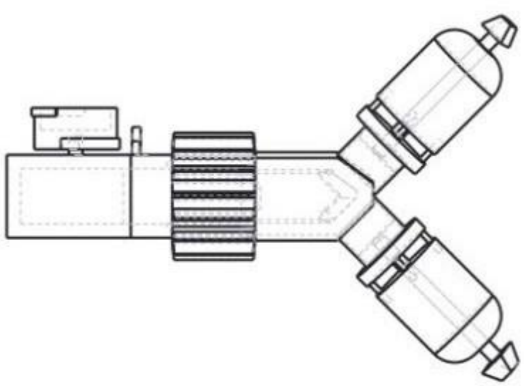
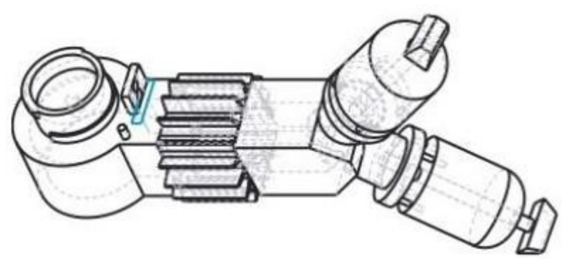
APPENDIX I: CAD DRAWING

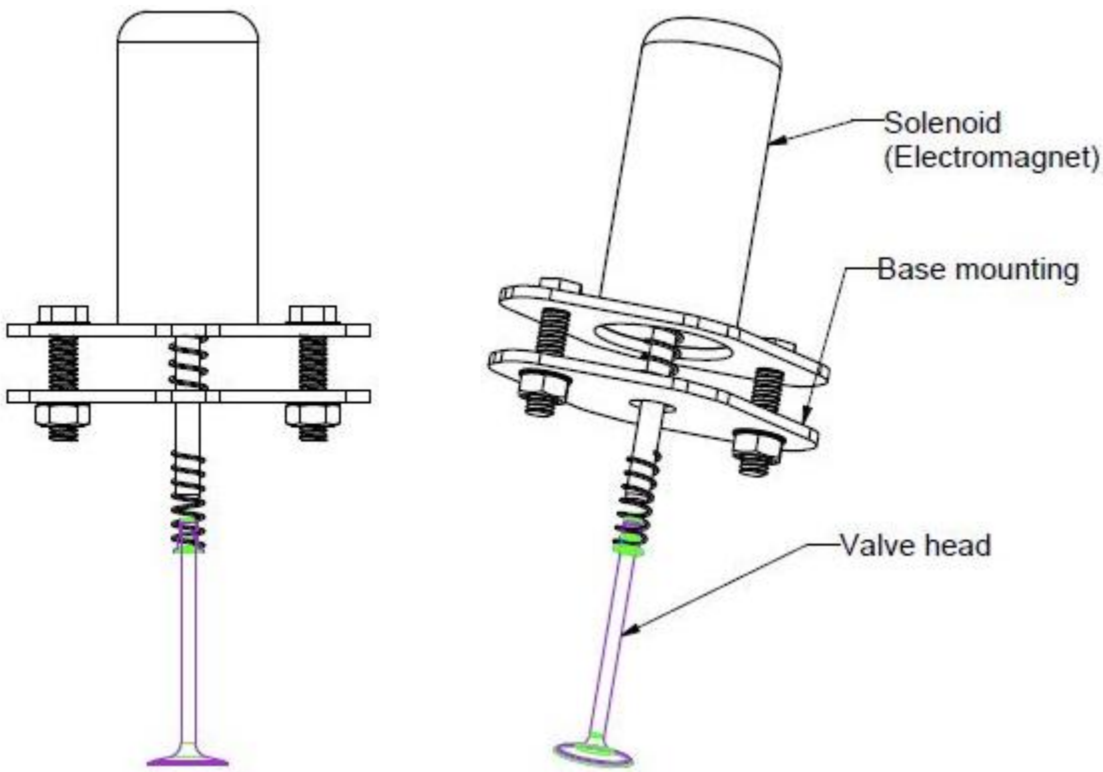
Arrangement of Solenoid on Engine Head







Installment of Electromagnets



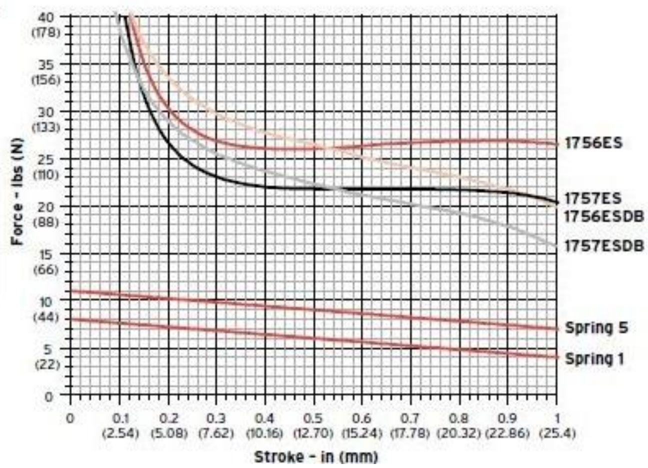
APPENDIX II: DATA

Woodward Solenoid

Solenoids

1750 Push Series

Models 1756ES, 1756ESDB, 1757ES & 1757ESDB dual coil solenoids.
Externally switched push models available with double boot
Push Force Range: 16-26 lbs (71-116 N)
Hold Force Range: 35-56 lbs (156-249 N)



Specifications:

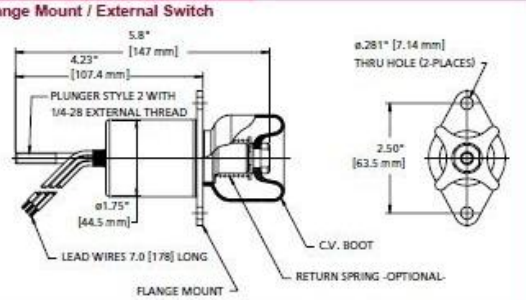
Temperature Range	-40°F to +250°F (-40°C to +121°C)
Weight	1.5 lbs (0.7 kg)

Return Spring

Model	Force @ 1"
S1 Light	4-8 lbs
S5 Medium	7-11 lbs

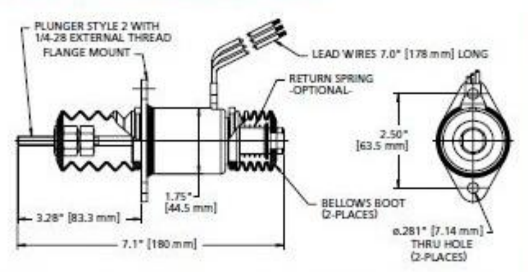
MOUNTING STYLE A

Flange Mount / External Switch



MOUNTING STYLE A

Flange Mount / External Switch, Double Boot



Cam Profile

Degree	IVL (mm)	EVL (mm)	Degree	IVL (mm)	EVL (mm)
0	0	0	195	5	0
15	0	0.55	210	4.36	0
30	0	1.1	225	2.95	0
45	0	1.9	240	1.9	0
60	0	2.95	255	1.1	0
75	0	4.36	270	0.55	0
90	0	5	285	0	0
105	0	4.35	300	0	0
120	0	2.95	315	0	0
135	0.25	1.25	330	0	0
150	1.25	0.35	345	0	0
165	2.95	0	360	0	0
180	4.35	0			

Table 3: Engine cam profile

Valve Spring UTM Test

Light spring			Hard spring			Parallel combination		
F (N)	d (mm)	k (N/mm)	F (N)	d (mm)	k (N/mm)	F (N)	d (mm)	k (N/mm)
5	1	5	15.25	1	15.25	20.25	1	20.25
10.28	2	5.14	31.354	2	15.677	41.634	2	20.817
15.87	3	5.29	48.4035	3	16.1345	64.2735	3	21.4245
21.02	4	5.255	64.111	4	16.02775	85.131	4	21.28275
25.85	5	5.17	78.8425	5	15.7685	104.6925	5	20.9385
31.2	6	5.2	95.16	6	15.86	126.36	6	21.06

Table 4: Valve spring UTM Test results

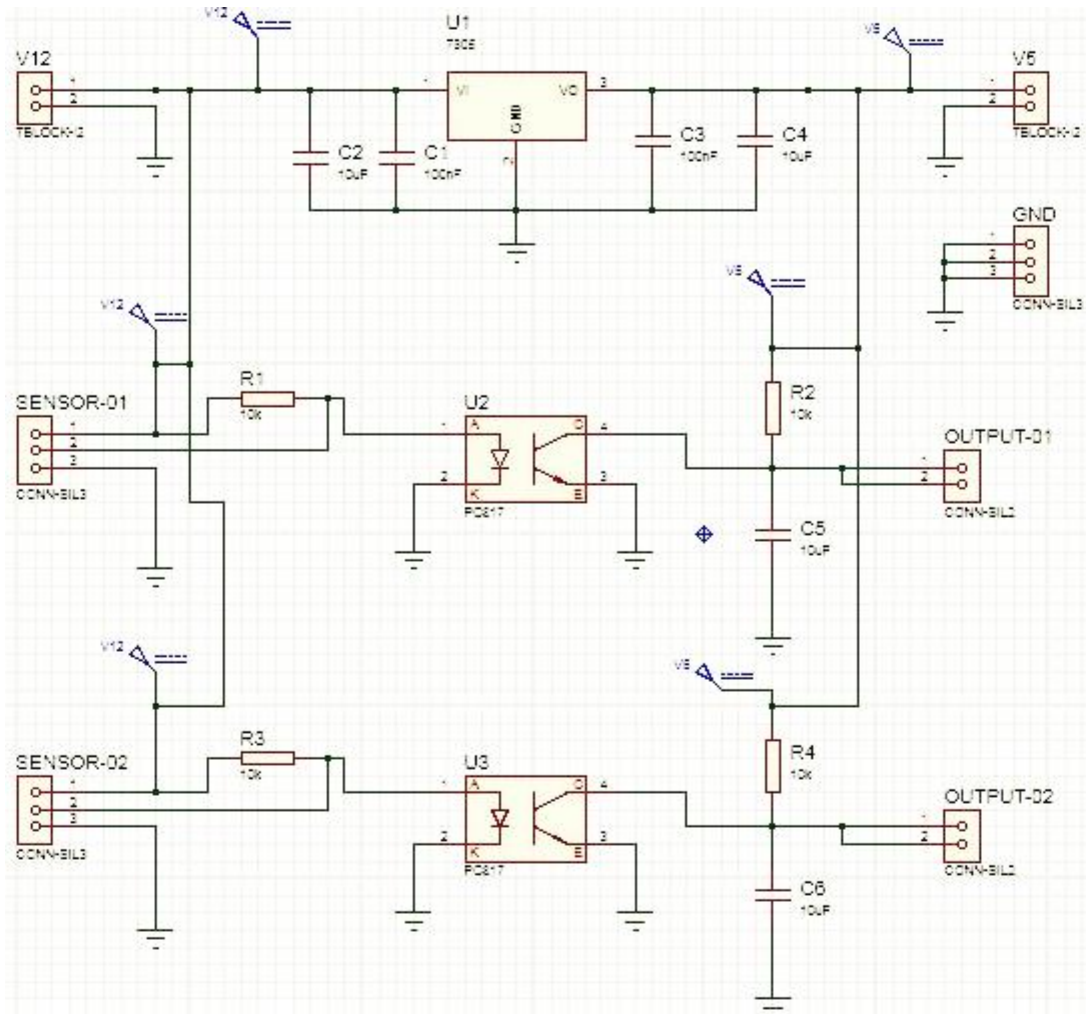
Dynamometer Test

Speed	Torque (Nm)	Power (kW)	Fuel (g/min)
800	6.76	0.57	6.64
1000	7.63	0.80	6.8
1500	7.83	1.23	7.2
2000	8.31	1.74	8.1
2500	10.31	2.70	9

Table 5: Dynamometer Test Results of Engine

APPENDIX III: CIRCUIT AND CODE

Circuit Schematic



Program code

The complete programming code written in Arduino and implemented through microcontroller in this project can be found in the CD accompanying this project report.

```
// ----------------------------------
// CODE for Electronic Valve Train Engine
// ----------------------------------

// SENSOR INPUT PINS
// Intake Sensor must be attached to pin 2
// As pin 2 is External Interrupt 0
const byte IntakeSensor = 2;
// Exhaust Sensor must be attached to pin 3
// As pin 3 is External Interrupt 1
const byte ExhaustSensor = 3;

// VALVE OUTPUT PINS
const byte IntakeValve = 4;
const byte ExhaustValve = 5;
// Configure appropriately: INPUT SENSOR Active State
// Sensor Input Active Low
const boolean METAL_TRUE = LOW; // SENSOR Active - Low
```

```
const boolean METAL_FALSE = HIGH; // SENSOR De-Active - High

// Sensor Input Active High

const boolean METAL_TRUE = HIGH; // SENSOR Active - High

const boolean METAL_FALSE = LOW; // SENSOR De-Active - Low

// Configure appropriately: OUTPUT VALVE Active State


// Valve Output Active Low

const boolean VALVE_OPEN = LOW; // VALVE Active - Low

const boolean VALVE_CLOSE = HIGH; // VALVE De-Active - High

// Valve Output Active High

const boolean VALVE_OPEN = HIGH; // VALVE Active - High

const boolean VALVE_CLOSE = LOW; // VALVE De-Active - Low

boolean EngineStart = false;

boolean IntakeStrokeOdd = false;

boolean ExhaustStrokeOdd = false;

boolean flip = false;

volatile int INCountOpen = 0;

volatile int INCountClose = 0;
```

```
volatile int EXCountOpen = 0;

volatile int EXCountClose = 0;

boolean IntakeStroke = false;

boolean ExhaustStroke = true;

int prevValueIN = 0;

int prevValueEX = 0;

int curValueIN = 0;

int curValueEX = 0;

// Interrupt Service Routine (ISR) INTAKE SENSOR

void IntakeSensorChange ()

{

if (digitalRead (IntakeSensor) == METAL_TRUE){

IntakeStrokeOdd = !IntakeStrokeOdd;

if (IntakeStrokeOdd){

digitalWrite (IntakeValve, VALVE_OPEN);

INCountOpen++;

}

}
```

```
else{
//    // CLOSE INTAKE VALVE
digitalWrite (IntakeValve, VALVE_CLOSE);
INCountClose++;
}
}  // end of intakeSensorChange
// Interrupt Service Routine (ISR) EXHAUST SENSOR
void ExhaustSensorChange ()
{
if (digitalRead (ExhaustSensor) == METAL_TRUE){
if (ExhaustStrokeOdd){
//      // OPEN EXHAUST VALVE
digitalWrite (ExhaustValve, VALVE_OPEN);
EXCountOpen++;
}
ExhaustStrokeOdd = !ExhaustStrokeOdd;
}
else{
```

```
//    // CLOSE EXHAUST VALVE
digitalWrite (ExhaustValve, VALVE_CLOSE);
EXCountClose++;
}
}  // end of exhaustSensorChange
void setup ()
{
Serial.begin(9600);
Serial.println("Initializing ...");
  pinMode (IntakeValve, OUTPUT);
  pinMode (ExhaustValve, OUTPUT);
  digitalWrite (IntakeValve, VALVE_CLOSE);
  digitalWrite (ExhaustValve, VALVE_CLOSE);
//  HIGH -- LOW
  digitalWrite (IntakeSensor, HIGH);  // internal pull-up resistor
attachInterrupt (0, IntakeSensorChange, CHANGE);  // attach interrupt handler


  digitalWrite (ExhaustSensor, HIGH);  // internal pull-up resistor
```

```
attachInterrupt (1, ExhaustSensorChange, CHANGE);  // attach interrupt handler
  pinMode (LED_BUILTIN, OUTPUT);
  digitalWrite(LED_BUILTIN , HIGH);
if (digitalRead (IntakeSensor) == METAL_TRUE){
//    digitalWrite (IntakeValve, VALVE_OPEN);
}
//
if (digitalRead (ExhaustSensor) == METAL_TRUE){
ExhaustStrokeOdd = VALVE_OPEN;
}
  prevValueIN = digitalRead (IntakeSensor);
  prevValueEX = digitalRead (ExhaustSensor);
Serial.print("INTAKE STATUS : ");
Serial.println(digitalRead (IntakeSensor));
Serial.println(prevValueIN);
Serial.print("EXHAUST STATUS : ");
Serial.println(digitalRead (ExhaustSensor));
Serial.println(prevValueEX);
```

```
Serial.println("Start Reading");

Serial.println("-------------");

}  // end of setup



void loop ()

{

  curValueIN = digitalRead (IntakeSensor);

  curValueEX = digitalRead (ExhaustSensor);

  if (curValueIN != prevValueIN){

    prevValueIN = curValueIN;

Serial.print("INTAKE SENSOR : ");

Serial.println(curValueIN);

    if (curValueIN == METAL_TRUE){

      IntakeStroke = !IntakeStroke;

Serial.println(IntakeStroke);

      if (IntakeStroke){

        digitalWrite (IntakeValve, VALVE_OPEN);

Serial.print("INTAKE VALVE : ");
```

```
Serial.println("OPEN");
      }
    } else {
      digitalWrite (IntakeValve, VALVE_CLOSE);
Serial.print("INTAKE VALVE : ");
Serial.println("CLOSE");
    }
Serial.println("-------------");
  }
  if (curValueEX != prevValueEX){
    prevValueEX = curValueEX;
Serial.print("EXHAUST SENSOR : ");
Serial.println(curValueEX);
    if (curValueEX == METAL_TRUE){
      ExhaustStroke = !ExhaustStroke;
Serial.println(ExhaustStroke);
      if (ExhaustStroke){
        digitalWrite (ExhaustValve, VALVE_OPEN);
```

```
Serial.print("EXHAUST VALVE : ");
Serial.println("OPEN");
      }
    } else {
      digitalWrite (ExhaustValve, VALVE_CLOSE);
Serial.print("EXHAUST VALVE : ");
Serial.println("CLOSE");
    }
Serial.println("-------------");
  }
}
```

```
int IntakeValve = 4; // Intake Valve output port

int ExhaustValve = 5; // Exhaust Valve output port


// Set RPM of the Engine

// -----------------------

int RPM = 2000;


// Valve Output Active Low

const boolean VALVE_OPEN = LOW; // Valve Active - Low

const boolean VALVE_CLOSE = HIGH; // Valve De-Active - High


// Valve Output Active High

//const boolean VALVE_OPEN = HIGH; // Valve Active - High

//const boolean VALVE_CLOSE = LOW; // Valve De-Active - Low


// -------------------- //

float TDC_BDC = 0;
```

```
unsigned long strokeTime = 0;
//unsigned long inOnTime = 0;
//unsigned long exOnTime = 0;
//unsigned long inOffTime = 0;
//unsigned long exOffTime = 0;

void setup() {
  pinMode(LED_BUILTIN , OUTPUT );
  pinMode(IntakeValve , OUTPUT );
  pinMode(ExhaustValve , OUTPUT );
  digitalWrite(LED_BUILTIN , HIGH);
  digitalWrite(IntakeValve , VALVE_CLOSE);
  digitalWrite(ExhaustValve , VALVE_CLOSE);

  TDC_BDC = 30 * 1000 ; // milli-seconds
  TDC_BDC = TDC_BDC / RPM ;
  strokeTime = TDC_BDC;
}
```

```
void loop() {

  // --- Stroke 1 ---

  digitalWrite(IntakeValve , VALVE_OPEN);

  digitalWrite(ExhaustValve , VALVE_CLOSE);

  delay (strokeTime);



  // --- Stroke 2 ---

  digitalWrite(IntakeValve , VALVE_CLOSE);

//  digitalWrite(ExhaustValve , VALVE_CLOSE);

  delay (strokeTime);



  // --- Stroke 3 ---

//  digitalWrite(IntakeValve , VALVE_CLOSE);

//  digitalWrite(ExhaustValve , VALVE_CLOSE);

  delay (strokeTime);



  // --- Stroke 4 ---
```

```
//  digitalWrite(IntakeValve , VALVE_CLOSE);

  digitalWrite(ExhaustValve , VALVE_OPEN);

  delay (strokeTime);



}
```