Final Report

Variable Valve Timing

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Section 1: Introduction

Combustion engines help power our world. There are many diverse and practical uses for combustion engines, which explain why they haven't been replaced for over 100 years. The efficiency of these engines has increased dramatically with time. A century ago, internal combustion engines produced near 4 percent efficiency. Today, depending on the engine, the efficiency can vary around 35 to 40 percent. Many intuitive changes to the engine are still being developed. With a focus on increasing performance and decreasing pollutants the idea of modifying or creating a whole new alternative to the camshaft has gathered a lot of attention.

1.1 Description

With the complexity of our project, we have put in a lot of time in both researching and designing what we hope will produce a working prototype. This research has been in engine modifiability, actuator design, electronic control design, and engine testing. Much of the state of the art design is proprietary and not available to the public. This has made our job more difficult in that it is hard to find examples of what designs have been tried and which ones have succeeded.

Abstract

The goal of our senior project is to control the exhaust valve of a small one-cylinder 4-stroke gas engine with a computer controlled electromagnetic actuator. There are many possibilities in electromagnetic devices. We chose a push solenoid to actuate

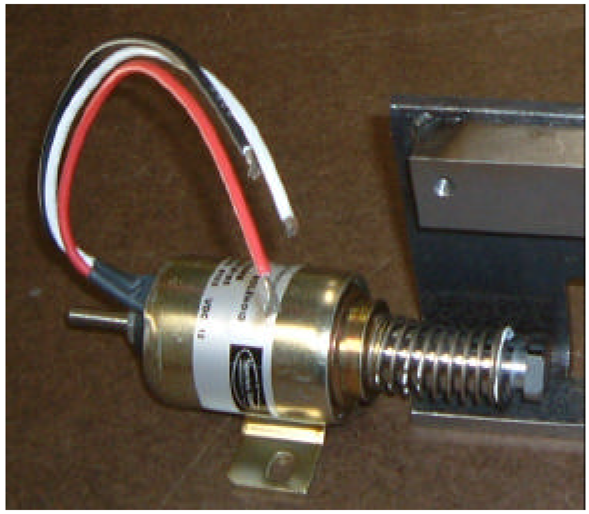
the exhaust valve. For controlling the solenoid, we chose a user interface with control options created in visual basic. The user interface communicates serially with a microprocessor. The microprocessor monitors and reports the engine's performance and control the opening/closing of the exhaust valve. Our ultimate goal is improved efficiency, decrease pollutants, and produce maximum power throughout the RPM range with a camless engine.

<u>Engine</u>

The project involved researching engines and selecting a design which will work well with our needed modifications. We chose a small one cylinder engine (Honda GC-160) for simplicity. The engine's design allows for easy access to the camshaft, rocker arms, and valves. This made it a practical choice for our modifications.

<u>Actuator</u>

In choosing an electromagnetic actuator, we tested and designed several different types of electromagnetic devices. We needed one that would give us both the force and frequency necessary to control the exhaust valve. We researched and talked to sales representatives about what actuators there are which would suit our needs. We ultimately chose a push model solenoid from Woodward.



In our design we have connected the solenoid directly to the valve stem, using no mechanical rocker arm system. This ensures that no forces will act on the valve stem in any direction but axially.

Electronic Control System

In controlling the solenoid with the microprocessor there are two variables we needed to know, the speed and the cycle. Knowing both of these variables we were able to control when the exhaust valve was actuated. To allow a control interface to the preprogrammed microprocessor we chose to use a computer interface. The computer and the microprocessor were able to communicate serially on an RS232 line. Having the control interface allows both the computer and a user to control the engine with complex control algorithms which are more difficult to program in assembly language.

Engine Testing

Initially we preformed tests on the stock engine to determine the engine's power specifications so we could compare them to how our prototype preformed. With this testing we could tell where in the RPM ranges we are gaining significant performance increases. We used the schools dynamometer, which is hooked up to the engine and applies a load using what ultimately is a water pump.

Objectives

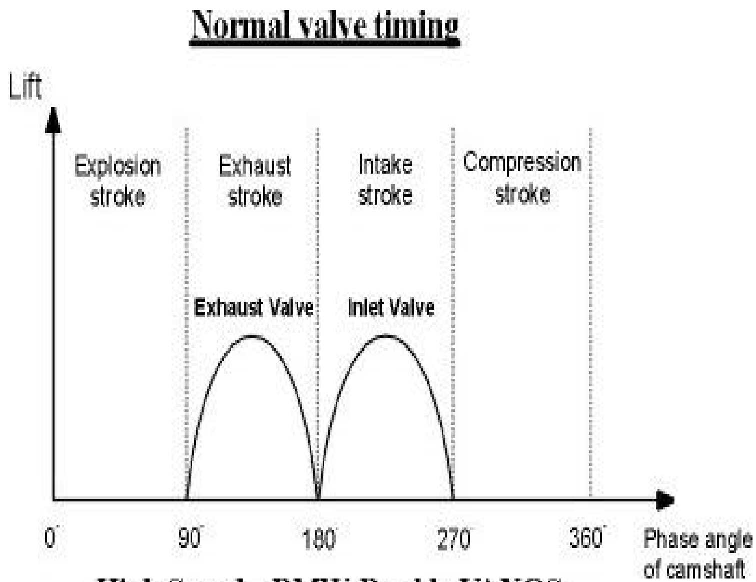
- Control the exhaust valve of a one cylinder, 4-stroke engine with a linear actuator and computer control system.

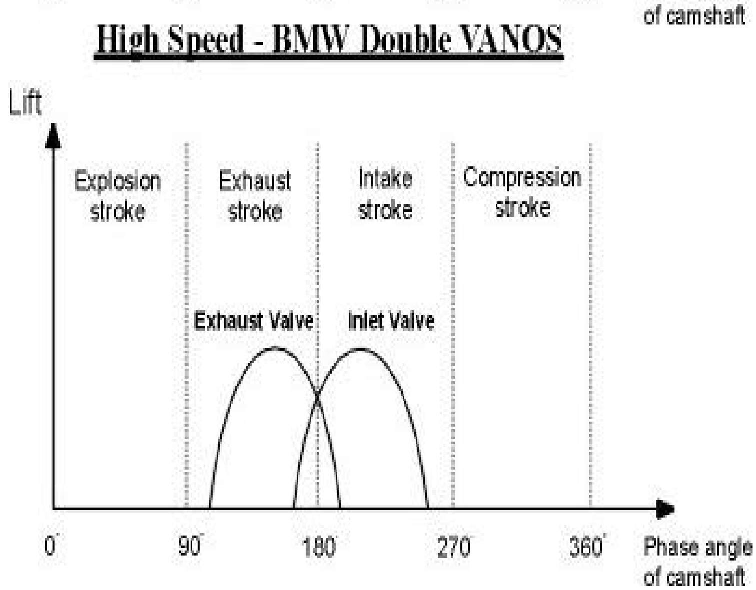
- Select a linear actuator that meets the required specifications of a stroke length of .25 inches, a seat force of 10 to 15 pounds, and a response time of 1 to 10 milliseconds.
- Construct an electronic control system which will be able to:
    - Read engine speeds from 0 to 3500 rpm
    - Vary valve timing depending on engine speed and operator inputs.
- Obtain gains in horsepower, torque, and efficiency of 2 percent.
- Construct and implement our design within a $500 budget.

1.2 Literature Review

Literature for our camless engine project was hard to find, because of only recent developments and also because or proprietary research. The first camless engine was built in 1999. We conducted some research on the internet about camless engines, and found resources concerning engines, solenoids and electromagnets from the library.

We also researched greatly on variable valve timing systems that are presently in use such as i-VTEC used by Honda, and VVTL-i used by Toyota. The key to reaping the benefits of a continuous variable valve train is to vary the valve overlap according to the RPM that the engine is running at. For example, at lower RPM, from about 1000-3000, little to no valve overlap should be used, this can be seen in the Normal Valve Timing graph. While at higher RPM, from about 3000-6000 more valve overlap should be used, this is illustrated in the High Speed Graph.





Our project only focused on implementing a Continuous Variable Valve Train on the exhaust valve of the engine. Our goal was to open the exhaust valve later in the cycle as the RPM increased to create more valve overlap for better breathing at high RPMs.

Siemens VDO Automotive, in partnership with BMW, built a prototype camless engine four years ago. In place of cams it used solenoids, electromagnetically controlled plungers, which are 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. For one thing, the solenoids and the additional computer power taxed the car's already overburdened electrical system. Gauthier said that cars would have to make a long-awaited move to 42-volt electrical systems (from the current 12 volts) before electronic valve control would be practical.

BMW's work proves that it is feasible to control the exhaust valves of an engine using electromagnets. We believe our project to be state of the art because there are no records found of electronically controlled valves being applied to small engines such as the one that we are working on.

We researched on-line to find more information about variable valve timing engines that are already being used in cars on the market. Although these systems use mechanical methods, we are planning to use the same concepts that they use to obtain more power from an engine by varying the lift and timing of the valve. When compared to the VTEC system, the solenoid or electromagnet system will be able to provide even more control in timing and lift.

Jon Myers showed our group a website called www.elctricvalves.com. The creators of this site made their own prototype engine that used an electromagnet system to control both the intake and exhaust valve. Unlike our design they used leverage and electromagnets to actuate both the exhaust and intake valve.

We found a SAE Newsletter which pertains to Lotus and Eaton working together to develop a camless engine. Lotus has signed a licensing agreement with Eaton for the production of Lotus' Active Valve Train (AVT). This technology promises to reduce engine emissions and improve fuel economy. On top of that engines have demonstrated increases in torque by up to 10%. The AVT system should be available for production by the year 2008. It will offer a level of valve control never seen before in production engines. The electro-hydraulic valve actuation technology enables virtually infinite manipulation of the timing, duration, and extent of lift for each valve. It will also be an enabler for new combustion processes. Lotus has a controlled auto-ignition and homogeneous-charge compression-ignition which is capable of reducing nitrogen oxides by up to 98%.

1.3 Solution

We chose to use a push solenoid because we had received as a generous gift in kind and we will save the time and cost in making our own electromagnet system. We had several alternatives to actuating the exhaust valve, but we felt the simplicity of our design was important. It allowed us an easy way to test the engine and see where future research could go in redesigning the actuator in the forces and timing needed.

For our project we chose to keep the camshaft for a reference to know when to fire the solenoid. The camshaft was also used to operate the intake valve since we only modified the exhaust valve.

Section 2: Design Process

Analysis and Experimental Work

There are many experiments that we will need to carry out before we actually start the design process. First and foremost, we need to test how fast the solenoid can open and close the valve. At high engine RPM's it will be critical that the solenoid we are using can open and close the valves at a very high rate in order to prevent the piston from coming in contact with the valve or the valve floating. We plan on testing this first before we ever mount the solenoid to the engine, by doing this we can see if it is possible to use a solenoid system or if we have to take an alternative route and possibly make our own electromagnet system.

We plan on testing the solenoid by connecting it to a function generator and increasing the frequency until the solenoid can no longer meet the requirements to function properly. We will begin testing as soon as we receive the solenoid from our sponsor, which should be as soon as a few weeks. Once the solenoid is mounted on the engine, we will use Visual Studio computer package as the controller for the solenoid. Once the engine is running, slight increases or decreases in timing and valve lift can provide substantial power gains depending on the RPM of the engine. Much of the project will be tested in a trail and error type method. For example we can find the timing and the amount of valve lift the engine has before modification, but in order to make it more efficient we have will just have to try different combinations of valve lift and timing to produce the most amount of power.

Unpredicted Outcomes

Our first problem occurred with the size of our engine. The engine we had was too small and did not have enough horsepower to operate under the loads of the dynamometer. We looked to alternative testing devices like the prony brake. After some testing, we soon found that the prony brake system did not provide us with accurate testing results. We also made some conclusions that the engine as a whole wasn't going to work for us for several reasons. First, the natural idle was at 4000 RPM. This would mean that the valve would have to open and close approximately 8 or 9 times a second. We didn't think that it would be possible to attain this amount of actuation with our resources. Second, we wouldn't ever be able to test the engine properly to know if the changes we made had actually had a positive effect. Finally, we would not able to receive the camshaft reference from the engine because the camshaft was not accessible.

Due to these factors we decided that it would be the best interest of the project to trade the engine that we had for a engine that would better profit our project. Through some more focused research we were able to locate the engine that seemed to solve many of the problems that we had been having. The engine that we selected to use was the Honda GC-160.

The Honda GC-160 is much larger and more powerful than the Honda GX-31, so we were able to dyno test, with Messiah's dynamometer and software package. It also has a much lower natural idle which is only at 1300 RPM. And finally it has an overhead camshaft, so we could easily add a camshaft sensor which was essential for the knowing when to trigger the exhaust valve. Overall the engine was a much better fit for the project.

Originally we planned on using an electromagnet system to control the valve. We purchased two electromagnets and assembled the system but it didn't perform the way that we expected it to. We found that when the electromagnets were more than a few tenths of an inch away from the attractor plate then they had little to no pulling effect. This greatly changed the whole project because we had to go with our second option of using the solenoid to control the valve and we weren't sure if the solenoid was strong enough to overpower the valve spring.

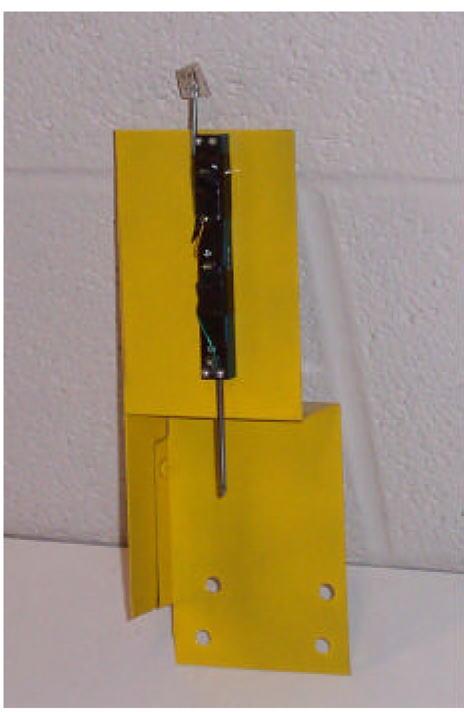
The original Hall Effect that was donated to us will not be used at all because it has an analog output. We wanted to use a hall effect with a digital output for easier communication, so we purchased two Hall Effects from Honeywell. One Hall Effect will read the RPM of the engine off a flywheel, and the other will act as a camshaft sensor. The Hall Effect sensor we chose is a completely sealed unit so we did not have to worry about dirt or oil interfering with the signals.

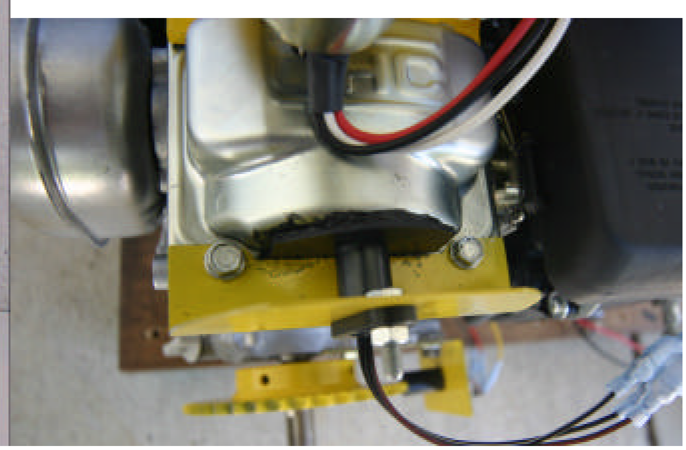
Section 3: Implementation

Construction

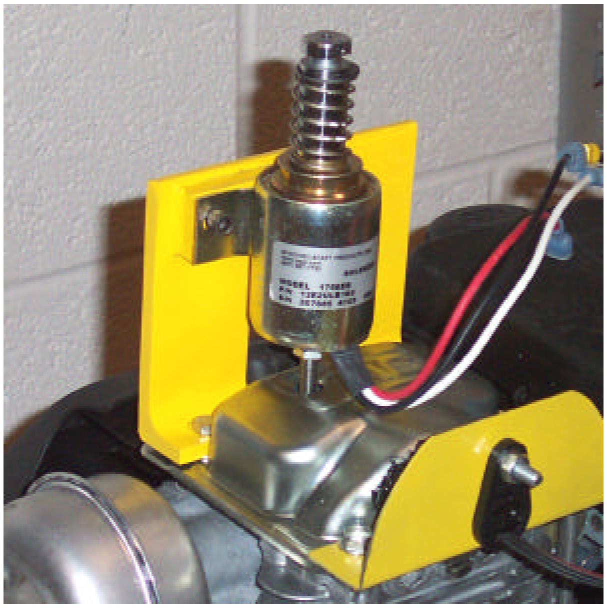
In designing this project, we learned to keep things as simple as they possibly could be while still maintaining the specifications that are needed for proper functionality. Only four brackets have been made for this project. We made two Hall Effect brackets, one for an rpm sensor (Fig 3.6, 3.7) and the other for camshaft sensor (Fig 3.8, 3.9). We also made a bracket for mounting the solenoid (Fig 3.4, 3.5), and another that mounted the linear potentiometer (Fig 3.10).

Both Hall Effect brackets and the linear potentiometer bracket were made from sheet metal. We did this because we wanted a simple design and we knew that there were not going to be any great loads on these parts either. The forming of sheet metal bracket is easy to do and takes considerably less time than machining or casting brackets. Because the designs for these brackets were very simple, we were able to build the parts in the least amount of time.





Keeping the same philosophy for easy designing and proper functionality, we built the solenoid bracket from a 4 inch angle iron and a mounting block which was welded to the angle iron, then the block was machined to proper tolerances. This provided us with more than enough strength to withstand the deflections that were made, while still allowing us to have tight tolerances necessary to place the solenoid plunger directly over the valve.



Overall the design did not change much and we were very fortunate to have a working prototype on our first design. All the brackets that we made we used and the original solenoid that we were given was used as our linear actuator. One problem that we had to overcome was the solenoid not being able to open exhaust valve due to all the compressive forces in the cylinder. To resolve this problem we made the solenoid impact the exhaust valve by simply changing the set position of the solenoid plunger to be a quarter inch away from the valve. The extra force created by the momentum of the plunger allowed the valve to open as needed. We slightly altered the solenoid by adding a rubber dampener to soften the blow of the stop nuts slamming back into the solenoid casing.

Control System

Our control system (Fig. 3.1) used several of the components already talked about. At the heart of the control system is the microprocessor. The microprocessor we chose was the Motorola 68HC11. The microprocessor was coded to receive inputs from the engine and also send signal to control the exhaust valve.

The two inputs the microprocessor needed was the speed and cycle of the engine. The speed allows us to know how long to open the engine and the cycle allow us to know when to open the engine.

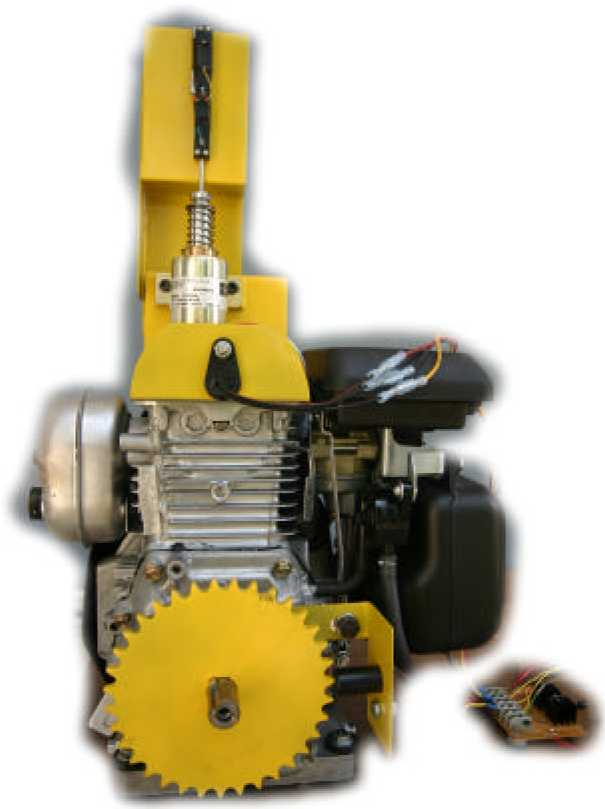
The microprocessor sent a signal to the solenoid driver as a square wave as to when to open the valve. The solenoid driver (Fig. 3.2) uses power mosfets to drive the solenoid. We used the power mosfets to work as relays except two huge benefits were they have instantaneous switching time and now bounce which is extremely important for quickly driving the solenoid.

The microprocessor has a computer interface (See Fig. 3.3) which was design in Microsoft Visual Studio .NET. This interface allowed us to make changes to the control system on the fly. This is important for both using the interface as a testing environment and using it to calculate complex algorithms as to when to actuate the valve. The interface can then send the data as bytes to the 8-bit microprocessor.

Operation

During operation we noticed that the engine would backfire through the intake about every other cycle. Using the linear potentiometer, we obtained measurements of the valve motion. The oscilloscope readout gave us a voltage signal proportional to the displacement of the valve. With this signal we could tell exactly what the valve is doing in relation to the cam timing. This data was useful in seeing how the solenoid reacts to different settings and in relation to what the exhaust valve should be doing. Through the use of the linear potentiometer we found that on certain cycles the solenoid does not fire correctly. What this means is that the exhaust valve does not open, and the combustion gases do not escape from the engine through the muffler like intended. The combustion products are instead, compressed and pushed out through the intake valve when it opens. We found that about every other cycle the valve didn't actuate probably because the solenoid plunger didn't have enough momentum to open valve since it was still coming up from the last stroke. Also, the solenoid might not have had enough force to crack the valve because of over heating.

Out of the 5 objectives we created for our project we achieved 4 of them. Our first objective, to construct and implement our design within a $500 budget was achieved by spending only $321.33 thanks to gifts in kind. Our next three objectives, to control the exhaust valve of an engine, select a linear actuator that meets specifications, and construct an electronic control system, deal with the design aspect of our project and were all achieved based on our initial testing results and running the engine. More specifically, for our fourth objective, the electronic control system we constructed is able to read engine speeds from 0 to 3600 rpm and vary the valve timing depending on engine speed and operator inputs. Our final objective, to obtain gains in horsepower, torque, and efficiency of 2% was not met because we were unable to produce the necessary test results to compare to our initial data. We are confident however, that this objective could be met with a redesign.



Section 4: Project Management

Scheduling

"He who every morning plans the transaction of the day and follows out that plan, carries a thread that will guide him through the maze of the most busy life. But where no plan is laid, where the disposal of time is surrendered merely to the chance of incidence, chaos will soon reign." Victor Hugo. Planning projects is necessary to keep long-term goals from becoming a burden. In order to stay on track of what needs to be done, and to complete jobs on time, it is important to have a timeline that reminds everyone involved what needs to be done and when it needs to be completed. The Gantt chart has become a common method to plan large projects. The Gantt chart clearly defines the due dates for all tasks involved to finish a project on time. For the variable valve-timing project, the Gantt chart was utilized as a task management tool. Throughout our project, two Gantt charts were created (see Appendix). The first chart was created at the beginning of the project and includes all tasks that needed to be completed from the beginning of the project to the end. The second chart was created in the aftermath of much unexpected delays in the project progress. This chart was used to bring into perspective what needed to be completed in the remaining time of the project. These charts are shown in the appendix of this report, and have been organized to clearly mark the important milestones throughout the completion of the project. Due to some of the delays that we encountered during our design and construction, we were behind schedule for most of our project. The main delays that impacted our schedule involved testing the performance of our engine and changing which engine we used. When we found that the dynamometer the school posses could not measure down to the scale we needed we looked for other ways to measure the performance of the engine. We looked to prony brakes and other measurement devices but none was successful. Over winter break, we found our solution was to implement our design on a larger engine. This involved redesigning many parts and almost starting fresh in our design. In spite of the delays, we were able to accomplish four out of five of our objectives.

Delegation of responsibility

A leadership role involves organization and control. Delegation of responsibility is dividing the necessary work to complete a project into equal shares for all the members to complete. The goal is to give an equal amount of work to each member in the areas where they excel. Knowing the strengths and weaknesses of all the members is important to a leader when distributing the workload. Each task needs careful handling to be sure that the person responsible can complete it in the time estimated. All the tasks given to one person constitute their "Job". Each Job should be an even workload over the course of the project and be equal to other Jobs. Distributing the workload evenly between the group members will not only keep members happy but also insure that no one is doing too little or too much. Jon Ashley's job is team leader; this involves organizing the efforts of the whole team in a way that maximizes their productivity. Anne Marek and Jon Ashley are responsible for a testing procedure and apparatus to test the engine for its performance when the work is completed on it. Steve Hearn is responsible for the computer program, the microprocessor programming, and the solenoid driver that will operate the valve. The mounting and wiring of the solenoid to the engine are in the hands of Bruce Mitchell and Steve Hearn. Every person took responsibility for the part of the project that they were responsible for. It was the responsibility of that person to complete the tasks associated with their part and seek help when they did not have the required knowledge to complete that task.

Section 5: Budget

Budget

Expense List		
Items	**Cost**	**Gifts-in-Kind**
Engine	$193.98	
Engine Manual	$23.85	
Engine Testing		
Materials	$10.00	
Solenoid	$50.00	X
RPM Sensor	$20.00	
Timing Sensor	$20.00	
Linear Resistor	$220.00	X
Professional Consultation	$30.00/hr.	X
Engine Parts/ Maintainence	$43.50	
Camshaft Replacements (2)	$40.00	X
Electronic Components	$10.00	
Electromagnets	$60.00	
Microprocessor	$150.00	X
Raw Materials	$10.00	X
Visual Basic Program	$1,500	X
Miscellaneous Expenses	$30.00	
(photocopies, phone use, etc)		
	Total Costs=	**$2371.33**
	Amt. in Donations=	$2000.00
	Actual Cost=	**$371.33**

Funding

Sources of Funding	Amount of Funding	Gifts-in-kind
Engineering Department	$500.00	
Woodward	$80.00	X
Paul B. Moyer	$40.00	X
Dan Elliott	$220.00	X
Engineering Model Shop	$10.00	X
Engineering Electronics Lab	$1,650.00	X
Total Amount of Funding	**$2,500**	

Cost Difference: Prototype vs. Product

When comparing the cost invested into completing this project to the cost it would take to bring such a design into production, there are a few major differences. The most important difference comes from the initial parts we needed to buy to actually start the project such as the engine and its manual and spare replacement parts in case of error. In a normal production setting it would not be necessary to purchase these items. Also, if this design was to already be in production, then the testing phase would not be applicable and thus any costs towards that, such as purchasing sensors and linear resistors, would not need to be included. The components required are those being added on to the engine and those replacing the camshaft and mechanical arm on the valve. This would include the solenoid, microprocessor, electronic components, raw materials such as nuts, bolts and sheet metal, the initial purchase of the visual basic program if necessary, and labor costs. When considering just the cost of parts required, noting that they can be purchased in larger quantities at a cheaper cost, the projected cost of production for this design is approximately $200.00. This is extremely low compared to the amount we needed to spend, but again that is due to the fact that we had to purchase the fundamental components as well as those needed to construct our design.

Section 6: Conclusions

Looking back on this project, the overall outcome of results was successful. This can be evaluated by looking at how well our objectives were met. Out of the five objectives we created, we accomplished four of them. Our first objective, to construct and implement our design within a $500 budget was achieved by spending only $321.33. Our next three objectives, to control the exhaust valve of an engine, select a linear actuator that meets specifications, and construct an electronic control system, deal with the design aspect of our project and were all achieved based on our initial testing results and running of the engine. More specifically, for our fourth objective, the electronic control system we constructed is able to read engine speeds from 0 to 3600 rpm and vary the valve timing depending on engine speed and operator inputs. However, our final objective, to obtain gains in horsepower, torque, and efficiency of 2% was not met because we were unable to produce the necessary test results to compare to our initial data. Our engine was not stable enough to withstand the weight and pull force of a dynamometer, which meant we could not obtain the necessary results. We are confident though that this objective can be met if more time for testing is given.

There is a lot we could say about the need for variable valve timing. This design is very realistic for the future of the automotive industry as well as our education. With the recent developments in electromagnets, this technology has become more feasible with production models currently in development by BMW and Lotus. Currently, Lotus will be presenting a marketable design in 2008. This advanced technology is improving engines as we know them. On average, there is an increase in torque and efficiency using variable valve timing and a decrease in emissions, which has been a driving force to improve current emissions standards. Also, with the addition of this project to the engineering department, students will be able to have hands on experiences with the effects of variable valve timing on an engine, introducing students to cutting-edge technology.

Section 7: Recommendations for Future Work

Considering the accomplishments we have made completing this project, there is always still room for improvement. If we could have the opportunity to start over with our project, there are a few things we would do differently. From the very beginning we experienced problems with trying to obtain initial data from our engine. Rather than spending so much time experimenting with inaccurate variations of a dynamometer, we would look into trading in our engine or purchasing a different one right away that would comply with the school's dynamometer. It would also be beneficial to purchase more than one solenoid, because by the end of our testing the one solenoid we had was already beginning to fail. Although we were somewhat successful in controlling the exhaust valve of the engine and meeting our objectives, in hindsight it would have been easier to control the intake valve first considering the amount of groundwork we had to do.

This project also has a few opportunities for future work. The next greatest goal would be to convert the intake valve on the engine to electromagnetic control as well. Of course, a similar design and procedure could be followed to that of the exhaust valve. Once this is achieved and a control system is fully operable, the camshaft can be completely removed. Right now the camshaft is still in place to assist with the timing of the linear actuator. There is also the possibility of modifying the solenoid used. More extensive research could be done on how to decrease the weight as well as control the spring or pull of the solenoid. Choosing a better solenoid will help resolve the problems we have had with our current solenoid overheating and inconsistently providing enough impact force. In addition, our present timing algorithm is operable; however, there is room for improvement on the precision of the timing as it moves across the rpm's.

Finally, there is improving the overall setup of our design so it can be used for research and experimental purposes within the Messiah College Engineering Department.

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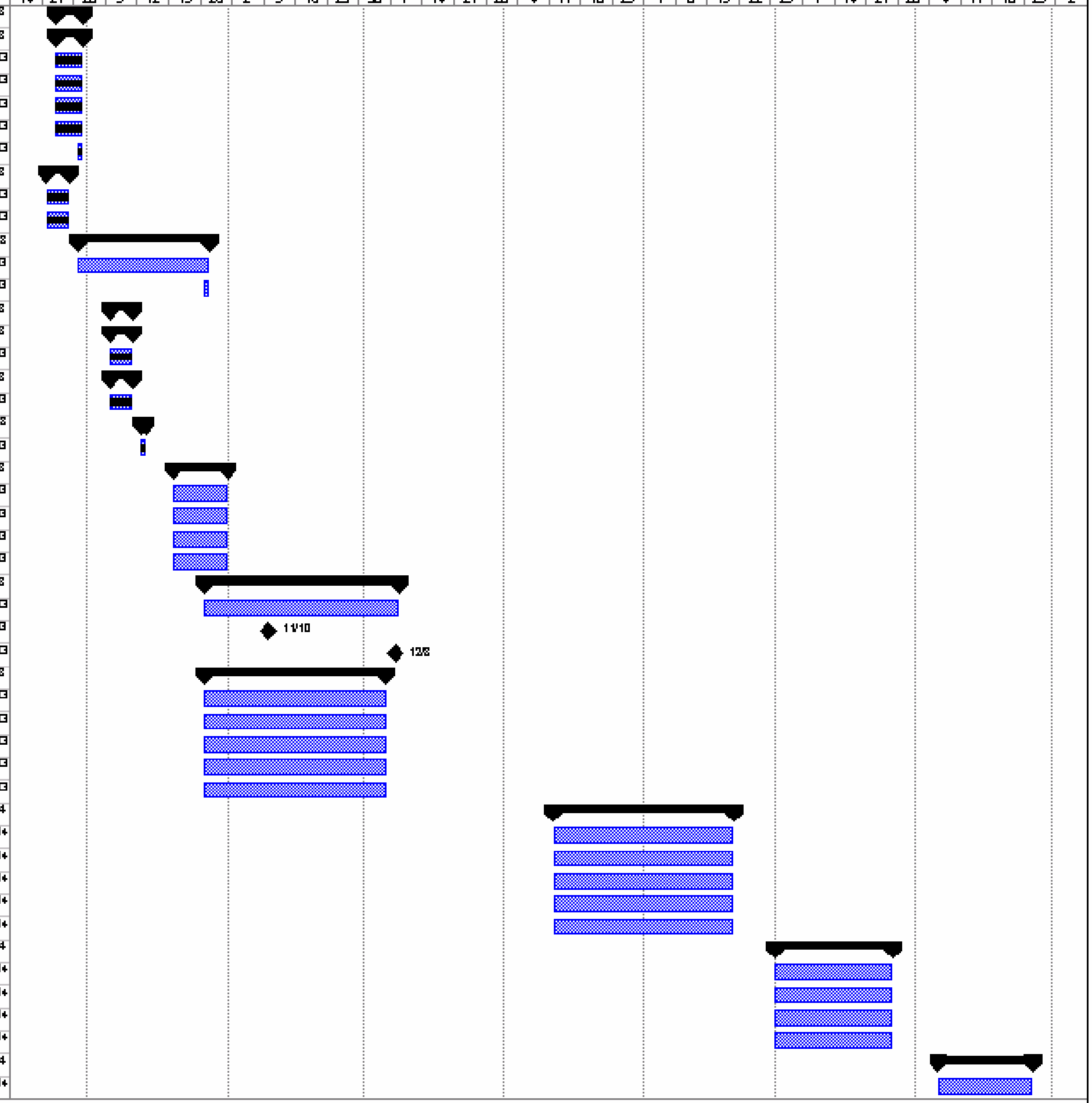
SBE, LLC, http://www.electronicvalves.com/, November, 2003

Appendix 1. Gantt Chart

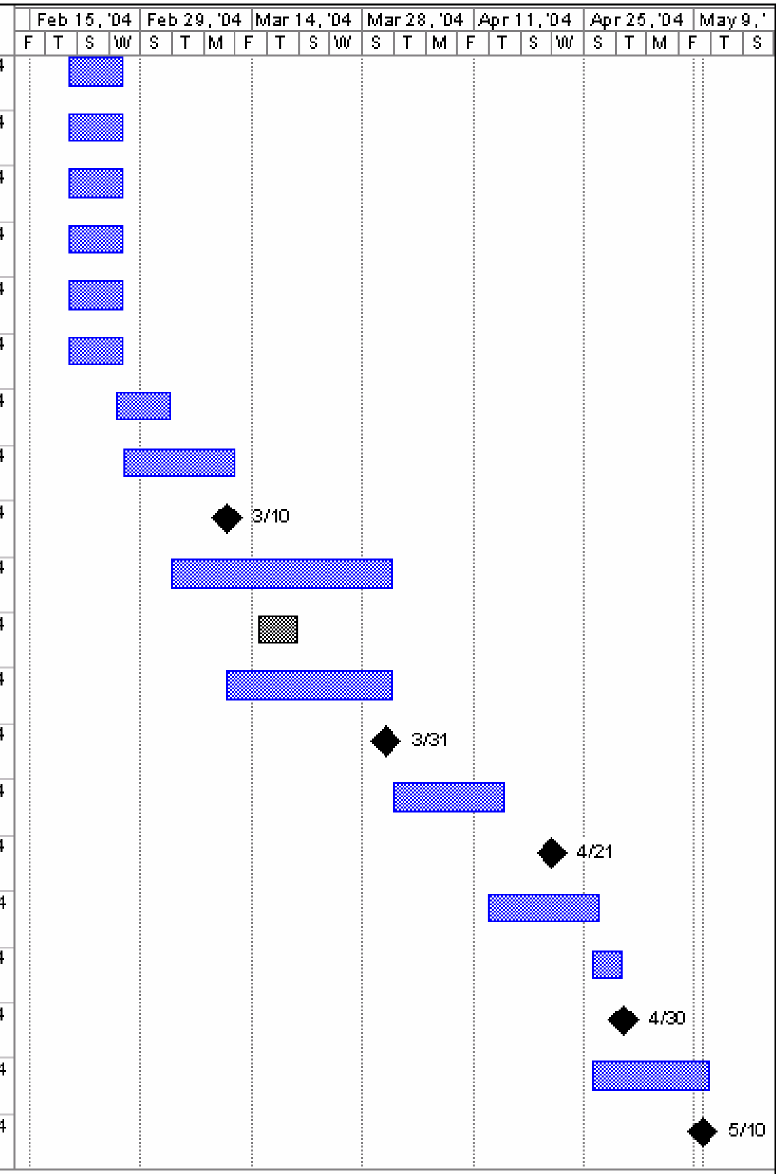
1	**Project Proposal**	4 days	Wed 9/24/03	Mon 9/29/03
2	Write Project Proposal	4 days	Wed 9/24/03	Mon 9/29/03
3	section 1	4 days	Wed 9/24/03	Mon 9/29/03
4	Section 2	4 days	Wed 9/24/03	Mon 9/29/03
5	section 3, 4	4 days	Wed 9/24/03	Mon 9/29/03
6	Section 5, 6	4 days	Wed 9/24/03	Mon 9/29/03
7	Due date of project proposal	1 day	Mon 9/29/03	Mon 9/29/03
8	**Research**	5 days	Mon 9/22/03	Fri 9/26/03
9	Research state of the art	5 days	Mon 9/22/03	Fri 9/26/03
10	Research patents	5 days	Mon 9/22/03	Fri 9/26/03
11	**Specification Sheets**	21 days	Mon 9/29/03	Mon 10/27/03
12	Write specification sheets	21 days	Mon 9/29/03	Mon 10/27/03
13	Specification sheets due	1 day	Mon 10/27/03	Mon 10/27/03
14	**Order Parts**	5 days	Mon 10/6/03	Fri 10/10/03
15	Engine	5 days	Mon 10/6/03	Fri 10/10/03
16	Choose Engine and find the cheapest one a	5 days	Mon 10/6/03	Fri 10/10/03
17	Solenoids	5 days	Mon 10/6/03	Fri 10/10/03
18	Choose solenoids and create Order number	5 days	Mon 10/6/03	Fri 10/10/03
19	**Mid Semester Progress review**	1 day	Mon 10/13/03	Mon 10/13/03
20	Log Books Due	1 day	Mon 10/13/03	Mon 10/13/03
21	**Testing of Stock Engine**	10 days	Mon 10/20/03	Fri 10/31/03
22	Efficiency	10 days	Mon 10/20/03	Fri 10/31/03
23	Torque	10 days	Mon 10/20/03	Fri 10/31/03
24	Horsepower	10 days	Mon 10/20/03	Fri 10/31/03
25	Noise Level	10 days	Mon 10/20/03	Fri 10/31/03
26	**Engineering Design Report**	31 days	Mon 10/27/03	Mon 12/8/03
27	Write engineering design report	31 days	Mon 10/27/03	Mon 12/8/03
28	Review progress on engineering design report (F	0 days	Mon 11/10/03	Mon 11/10/03
29	Engineering design report due - final draft	0 days	Mon 12/8/03	Mon 12/8/03
30	**Design Of Prototype**	30 days	Mon 10/27/03	Fri 12/5/03
31	Linear actuator design or choose which linear act	30 days	Mon 10/27/03	Fri 12/5/03
32	Mounting bracket for linear actuator	30 days	Mon 10/27/03	Fri 12/5/03
33	Attachment of valve to linear actuator	30 days	Mon 10/27/03	Fri 12/5/03
34	Computer control program	30 days	Mon 10/27/03	Fri 12/5/03
35	Wiring for linear actuator	30 days	Mon 10/27/03	Fri 12/5/03
36	**Build Prototype Engine**	30 days	Mon 1/12/04	Fri 2/20/04
37	Linear actuator.	30 days	Mon 1/12/04	Fri 2/20/04
38	Mounting bracket for linear actuator	30 days	Mon 1/12/04	Fri 2/20/04
39	Attachment of valve to linear actuator	30 days	Mon 1/12/04	Fri 2/20/04
40	Computer control program	30 days	Mon 1/12/04	Fri 2/20/04
41	Wiring for linear actuator	30 days	Mon 1/12/04	Fri 2/20/04
42	**Test Prototype Engine**	20 days	Mon 3/1/04	Fri 3/26/04
43	Efficiency	20 days	Mon 3/1/04	Fri 3/26/04
44	Torque	20 days	Mon 3/1/04	Fri 3/26/04
45	Horsepower	20 days	Mon 3/1/04	Fri 3/26/04
46	Noise Level	20 days	Mon 3/1/04	Fri 3/26/04
47	**Project Presentation**	15 days	Tue 4/6/04	Mon 4/26/04
48	Prepare Project Presentation	15 days	Tue 4/6/04	Mon 4/26/04



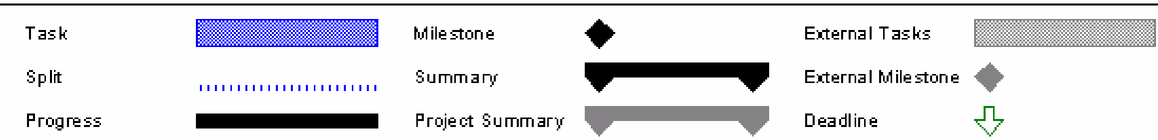
Project: Variable Valve Timing
Date: Mon 5/10/04

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

ID		Task Name	Duration	Start	Finish
1		Reasearch sensors for RPM and timing pickup.	5 days	Fri 2/20/04	Thu 2/26/04
2		Select RPM sensor	5 days?	Fri 2/20/04	Thu 2/26/04
3		Select timing sensor	5 days	Fri 2/20/04	Thu 2/26/04
4		Select gear	5 days?	Fri 2/20/04	Thu 2/26/04
5		Mount RPM sensor	5 days?	Fri 2/20/04	Thu 2/26/04
6		Mount timing sensor	5 days?	Fri 2/20/04	Thu 2/26/04
7		Rebuild driver and add heat sinks	5 days	Thu 2/26/04	Wed 3/3/04
8		Serial RS232 communication programing	10 days	Fri 2/27/04	Thu 3/11/04
9		Logbooks due prior to Spring Break	0 days	Wed 3/10/04	Wed 3/10/04
10		Valve timing program	20 days	Thu 3/4/04	Wed 3/31/04
11		Spring Break	5 days	Mon 3/15/04	Fri 3/19/04
12		Compose first draft of final report	15 days	Thu 3/11/04	Wed 3/31/04
13		First draft of final report due	0 days	Wed 3/31/04	Wed 3/31/04
14		Test preformance of modified engine	10 days	Thu 4/1/04	Wed 4/14/04
15		Review of progress on the final report	0 days	Wed 4/21/04	Wed 4/21/04
16		Prepare final presentation	10 days	Tue 4/13/04	Mon 4/26/04
17		Run-throughs of final presentations	4 days	Mon 4/26/04	Thu 4/29/04
18		Senior Design Project Final Presentations	0 days	Fri 4/30/04	Fri 4/30/04
19		Revise first draft of final report for final draft	11 days	Mon 4/26/04	Mon 5/10/04
20		Final written report and engineering logbooks due	0 days	Mon 5/10/04	Mon 5/10/04

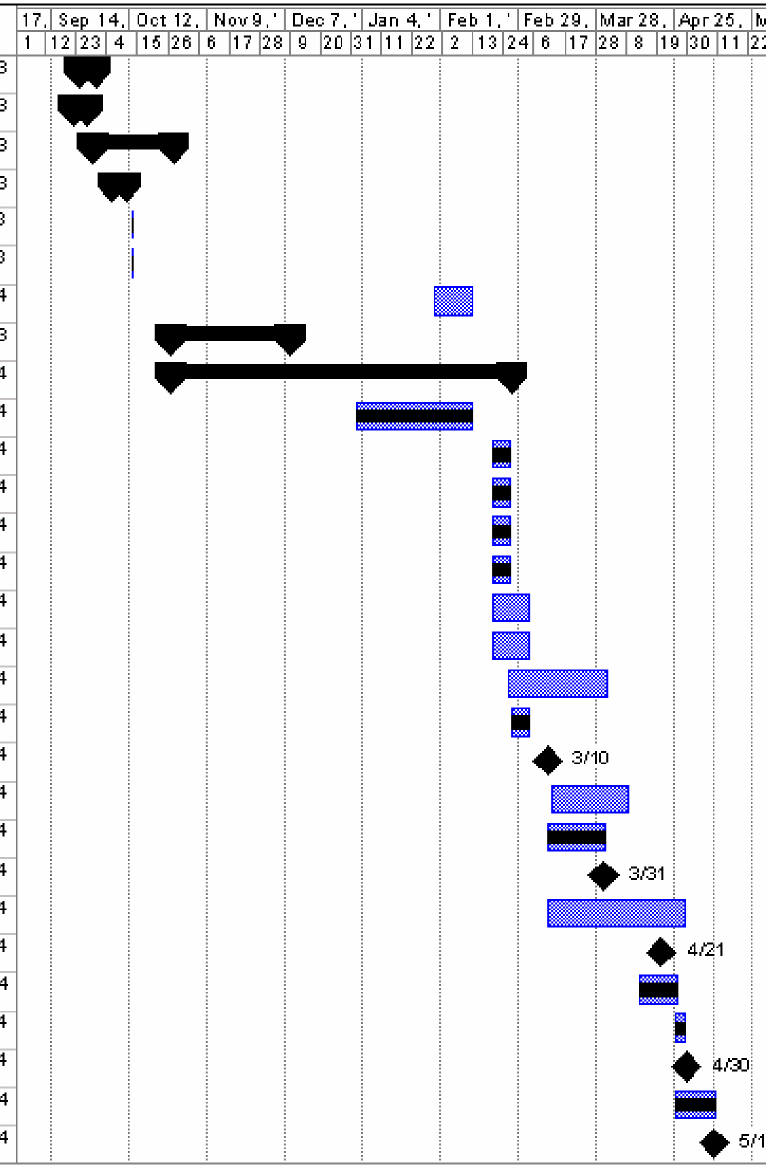


Project: spring VVT
Date: Mon 5/10/04



Modified Gantt Chart

ID	i	Task Name	Duration	Start	Finish
1	✓	Project Proposal	4 days	Wed 9/24/03	Mon 9/29/03
8	✓	Research	5 days	Mon 9/22/03	Fri 9/26/03
11	✓	Specification Sheets	21 days	Mon 9/29/03	Mon 10/27/03
14	✓	Order Parts	5 days	Mon 10/6/03	Fri 10/10/03
17	✓	Mid Semester Progress review	1 day	Mon 10/13/03	Mon 10/13/03
18	✓	Log Books Due	1 day	Mon 10/13/03	Mon 10/13/03
19		Testing of Stock Engine	10 days	Fri 1/30/04	Thu 2/12/04
20	✓	Engineering Design Report	31 days	Mon 10/27/03	Mon 12/8/03
24		Design Of Prototype	89 days	Mon 10/27/03	Thu 2/26/04
28	✓	Mounting bracket for linear actuator	30 days	Fri 1/2/04	Thu 2/12/04
29	✓	Reasearch sensors for RPM and timing pickup.	5 days	Fri 2/20/04	Thu 2/26/04
30	✓	Select RPM sensor	5 days?	Fri 2/20/04	Thu 2/26/04
31	✓	Select timing sensor	5 days	Fri 2/20/04	Thu 2/26/04
32	✓	Select gear	5 days?	Fri 2/20/04	Thu 2/26/04
33		Mount RPM sensor	10 days	Fri 2/20/04	Thu 3/4/04
34		Mount timing sensor	10 days	Fri 2/20/04	Thu 3/4/04
35		Rebuild driver and add heat sinks	26 days	Thu 2/26/04	Thu 4/1/04
36	✓	Serial RS232 communication programing	5 days	Fri 2/27/04	Thu 3/4/04
37	✓	Logbooks due prior to Spring Break	0 days	Wed 3/10/04	Wed 3/10/04
38		Valve timing program	20 days	Fri 3/12/04	Thu 4/8/04
39	✓	Compose first draft of final report	15 days	Thu 3/11/04	Wed 3/31/04
40	✓	First draft of final report due	0 days	Wed 3/31/04	Wed 3/31/04
41		Test preformance of modified engine	36 days	Thu 3/11/04	Thu 4/29/04
42	✓	Review of progress on the final report	0 days	Wed 4/21/04	Wed 4/21/04
43	✓	Prepare final presentation	10 days	Tue 4/13/04	Mon 4/26/04
44	✓	Run-throughs of final presentations	4 days	Mon 4/26/04	Thu 4/29/04
45	✓	Senior Design Project Final Presentations	0 days	Fri 4/30/04	Fri 4/30/04
46	✓	Revise first draft of final report for final draft	11 days	Mon 4/26/04	Mon 5/10/04
47	✓	Final report and engineering logbooks due	0 days	Mon 5/10/04	Mon 5/10/04



Project: final VVT
Date: Mon 5/10/04

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Actual Progress on completion of Tasks. Checked Tasks were completed on schedule.

Appendix 2. Specifications

a. Engine: Before Modification.
    i. Peak Horsepower: 1.5 hp at 7,000 rpm.
    ii. Peak Torque: 1.23 ft-lbs at 4,500 rpm.
    iii. Fuel Consumption: 0.55 lbs per hpH.
    iv. Peak Noise Level: 80 dB.
    v. Dimensions (L x W x H): 8.27 x 9.88 x 9.84 in.
    vi. Dry Weight: 7.5 lbs.
    vii. Ignition System: Transistorized Magneto.
    viii. Compression Ratio: 8.0 : 1
    ix. Valve Control: Camshaft with rods, rocker arms, and valve springs.
b. Linear Actuator.
    i. Stroke: 0.1 – 0.15 in.
    ii. Seat Force: 10 - 15 lbs.
    iii. Push Force: 10 - 15 lbs.
    iv. Dimensions (L x W x H): less than 4 x 4 x 7 in.
    v. Dry Weight: 1 - 3 lbs.
    vi. Response: 1 – 10 milliseconds
c. Engine: After Modification.
    i. Peak Horsepower: 1.5 – 2.0 hp at a given rpm.
    ii. Peak Torque: 1.2 – 1.7 ft-lbs at a given rpm.
    iii. Fuel Consumption: Max of 0.55 lbs per hpH.
    iv. Peak Noise Level: less than 100 dB.
    v. Dimensions (L x W x H): Less than 9 x 10 x 17 in.
    vi. Dry Weight: Less than 13 lbs.
    vii. Ignition System: Transistorized Magneto.
    viii. Compression Ratio: 8.0 : 1
    ix. Valve Control

1. Intake Valve: Camshaft with rods, rocker arms, and valve springs.
2. Exhaust Valve: Linear actuator with computer controlled signal.

d. Budget
    i. Total Expenses: less than $500
    ii. Total Cost: less than $2,000
e. Accuracy
    i. Stroke: ±0.01 in.
    ii. Solenoid Timing: ±1 deg. of desired timing
f. Safety
    i. Wear protective eye wear and ear plugs when operating engine
    ii. Perform operation in well ventilated area
    iii. Do not touch hot surfaces
    iv. Keep hands away from moving parts and pinch points
    v. Use care when refilling fluids into engine

Drawings and Schematics

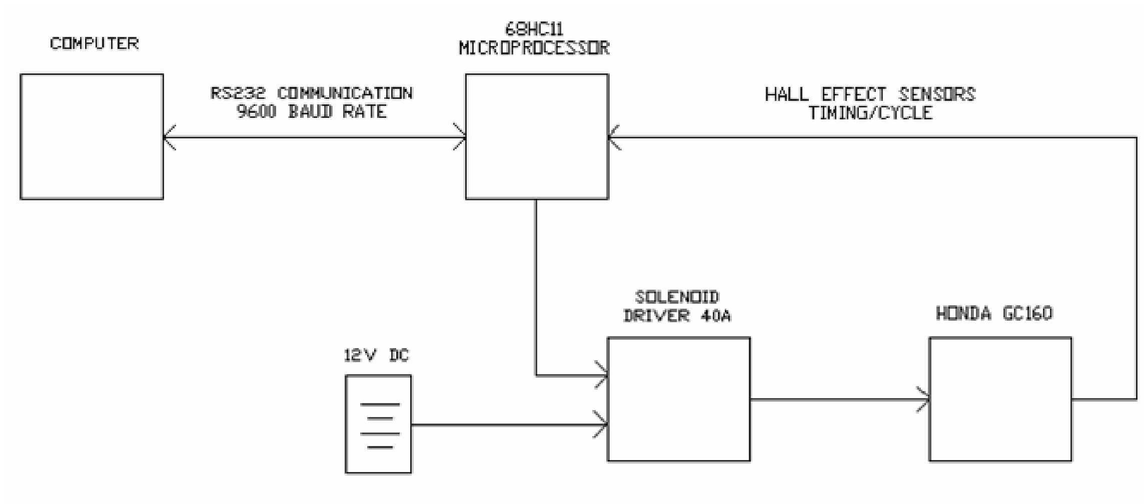


Fig 3.1: Block diagram of electronic control system

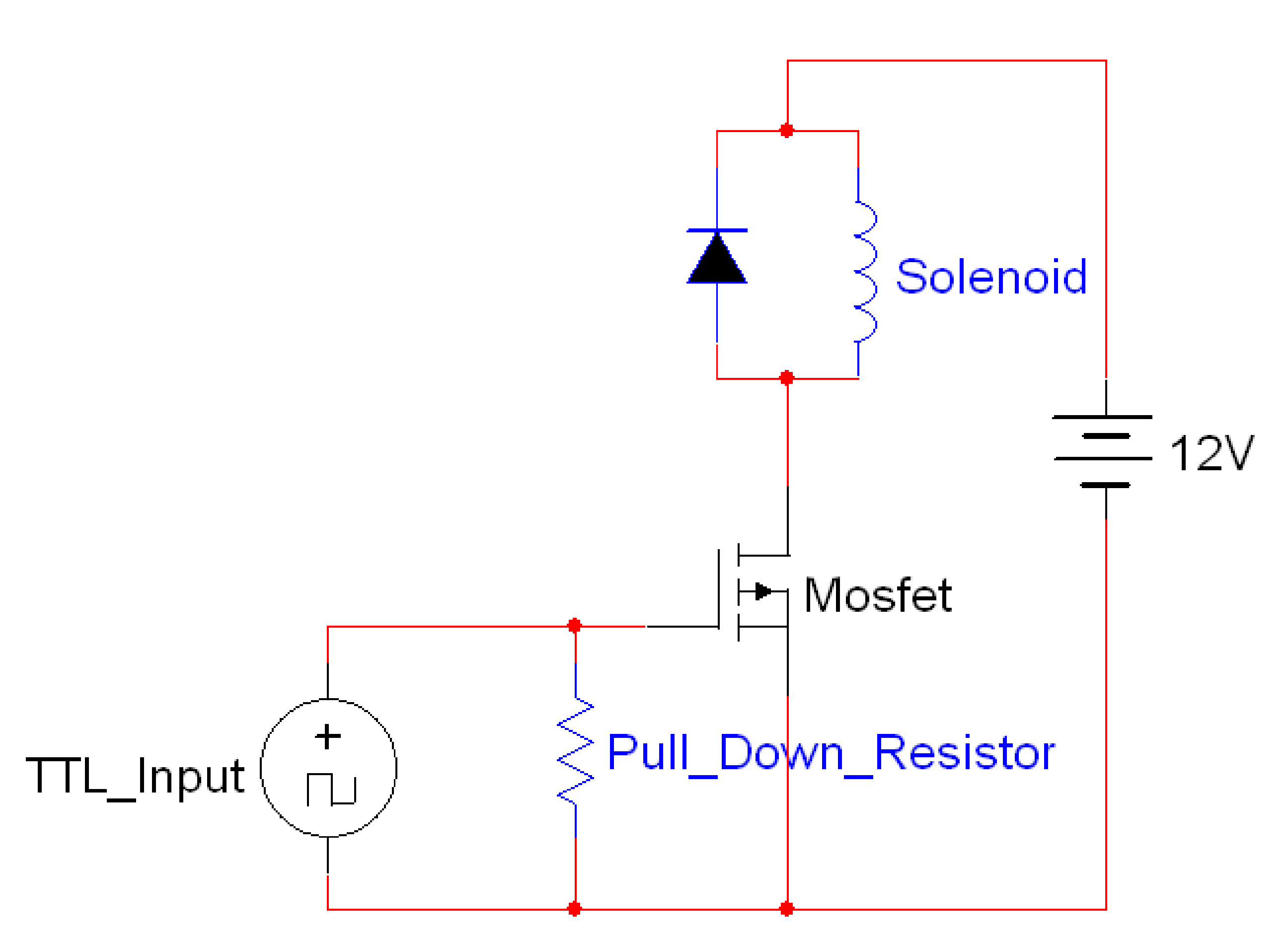


Fig 3.2: Solenoid driver circuit.

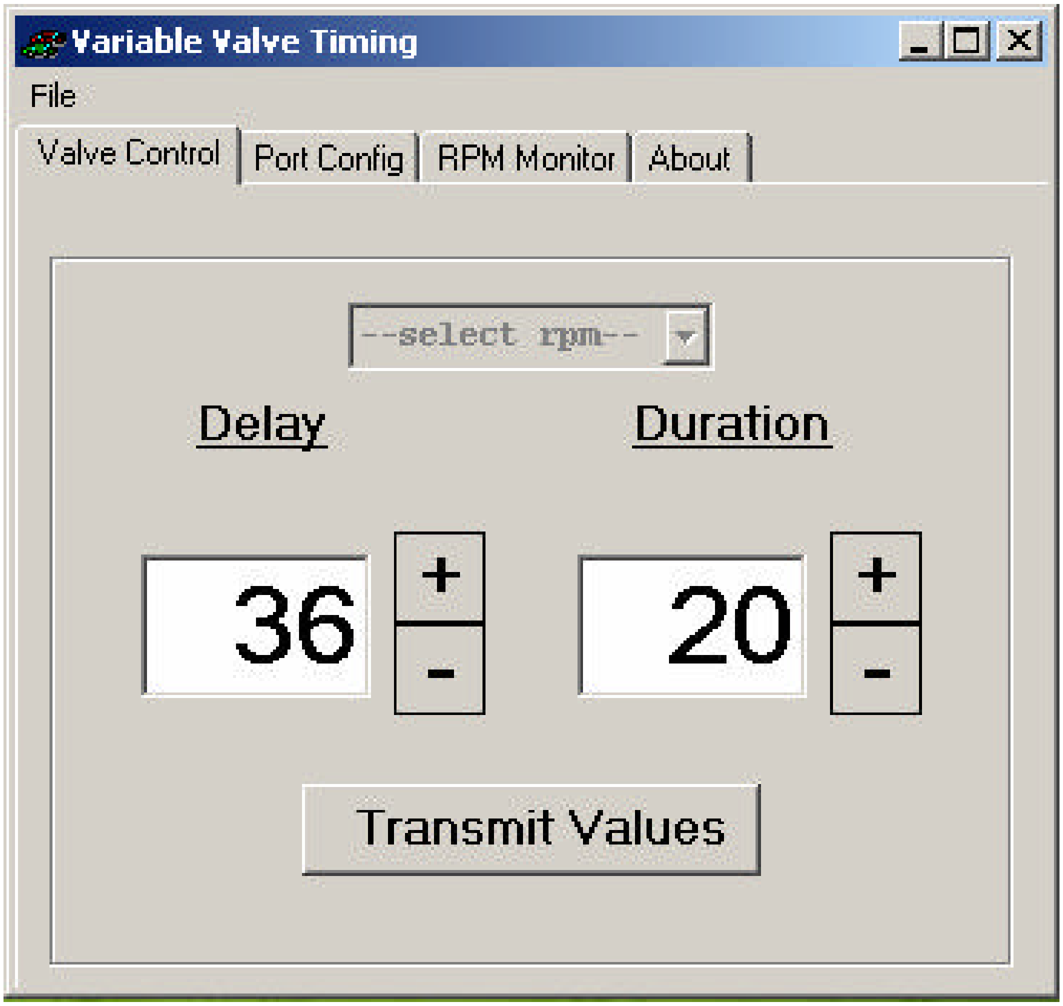


Fig 3.3: Computer user interface display.

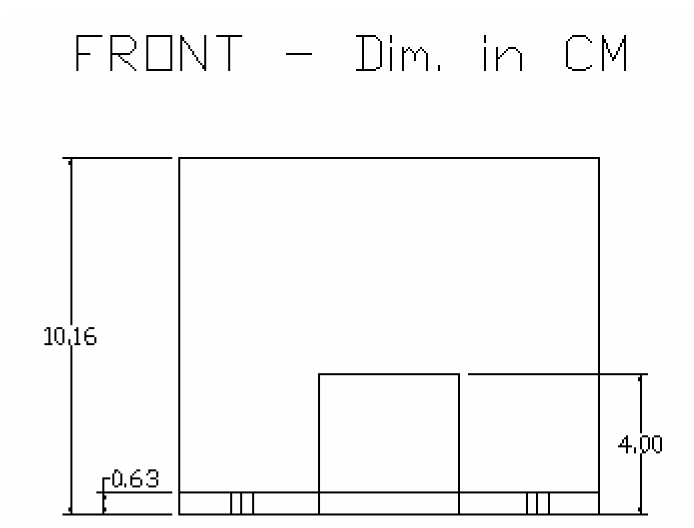


Fig 3.4: Solenoid mounting bracket, front dimensions.

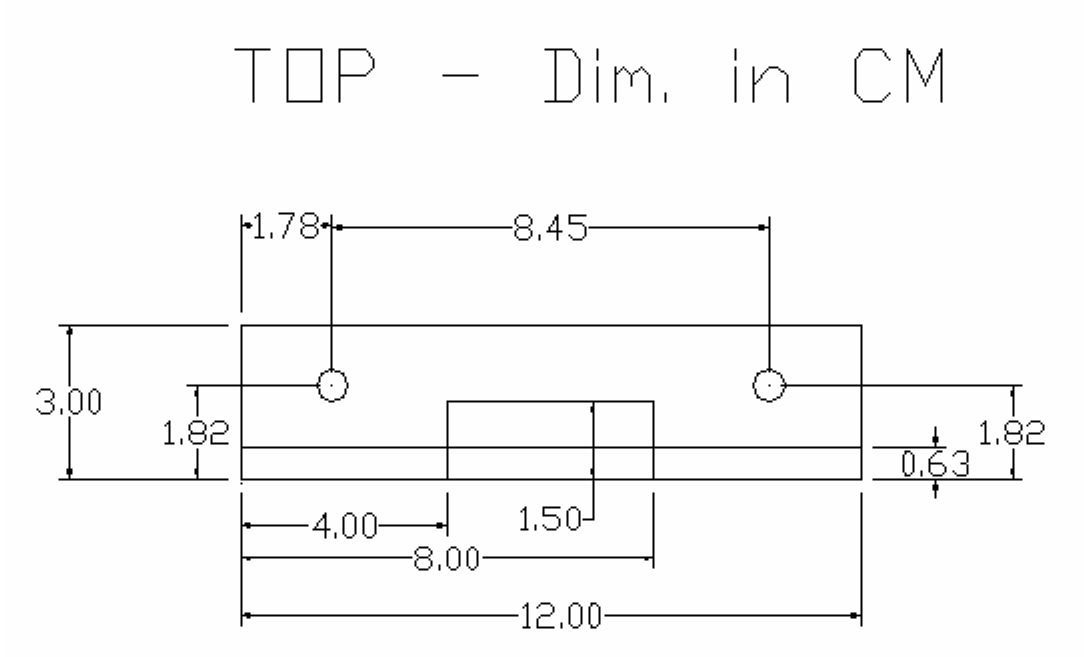


Fig 3.5: Solenoid mounting bracket, top dimensions.

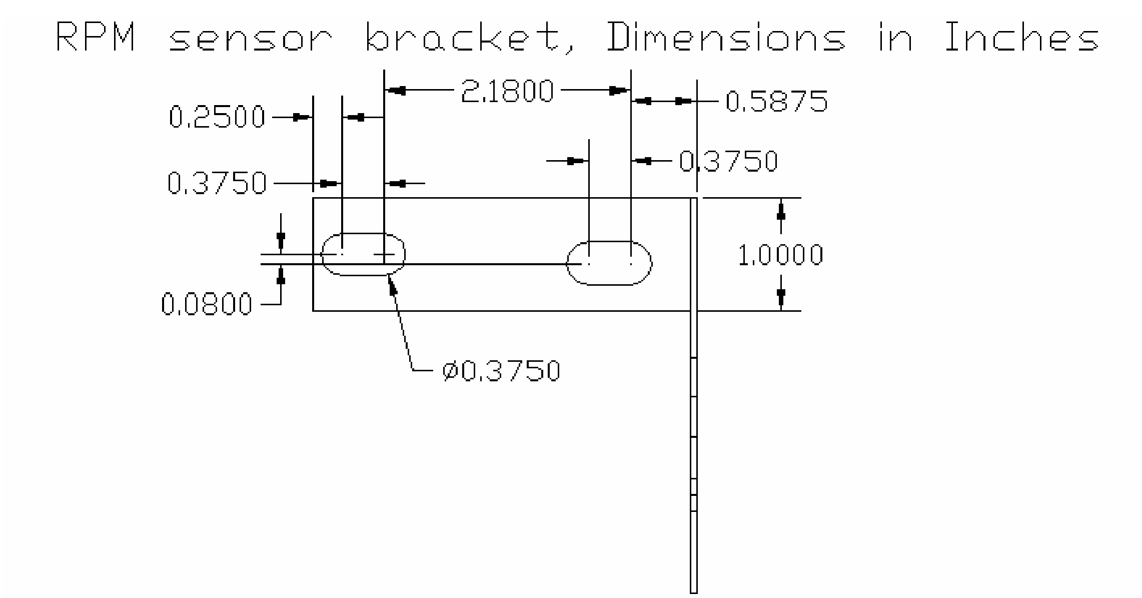


Fig 3.6: RPM sensor mounting bracket, front dimensions

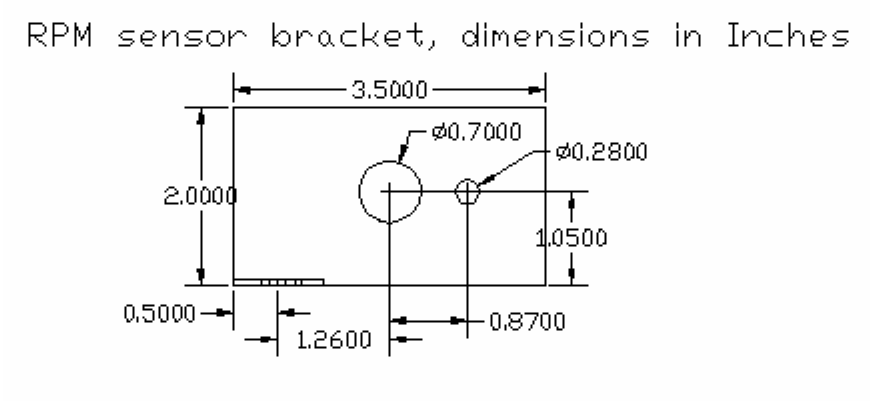


Fig 3.7: RPM sensor mounting bracket, side dimensions.

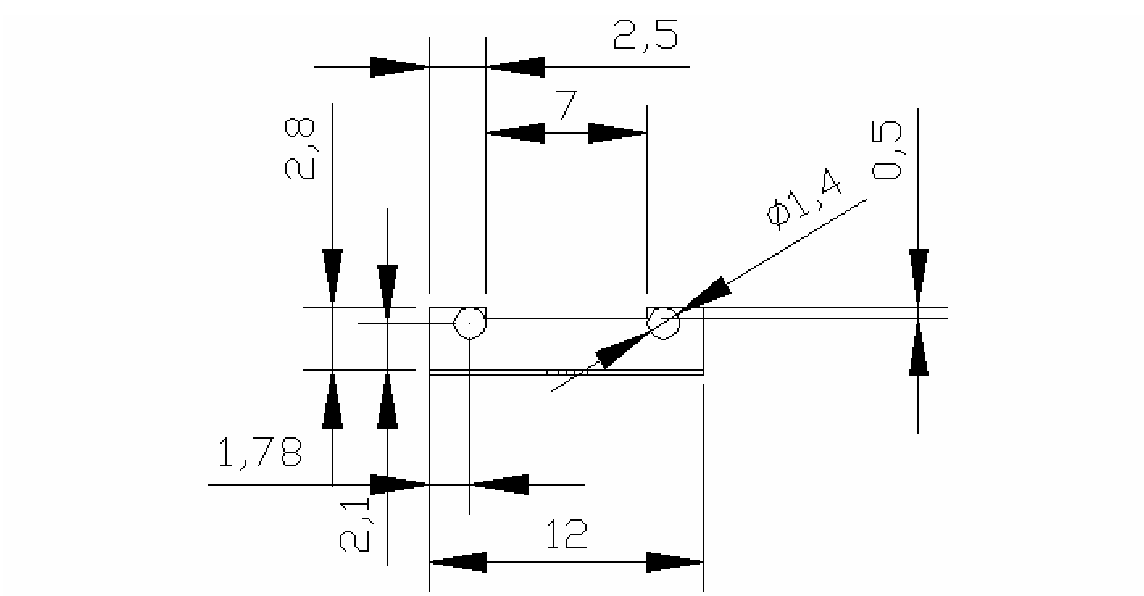


Fig 3.8: Cam sensor mounting bracket, top dimensions, dimensions in cm.

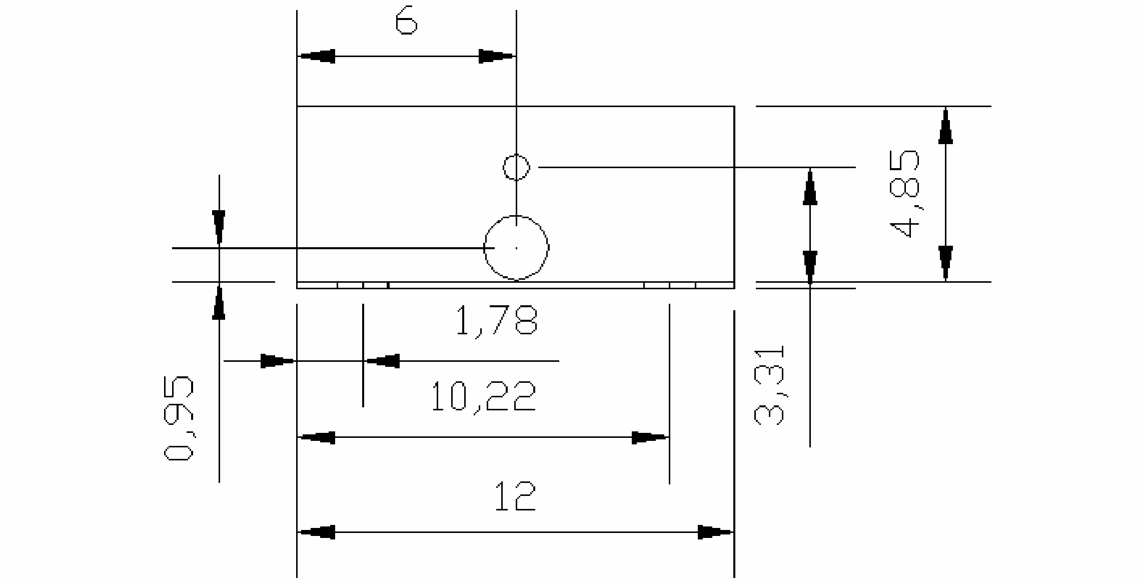


Fig 3.9: Cam sensor mounting bracket, front dimensions, dimensions in cm.

Test Data

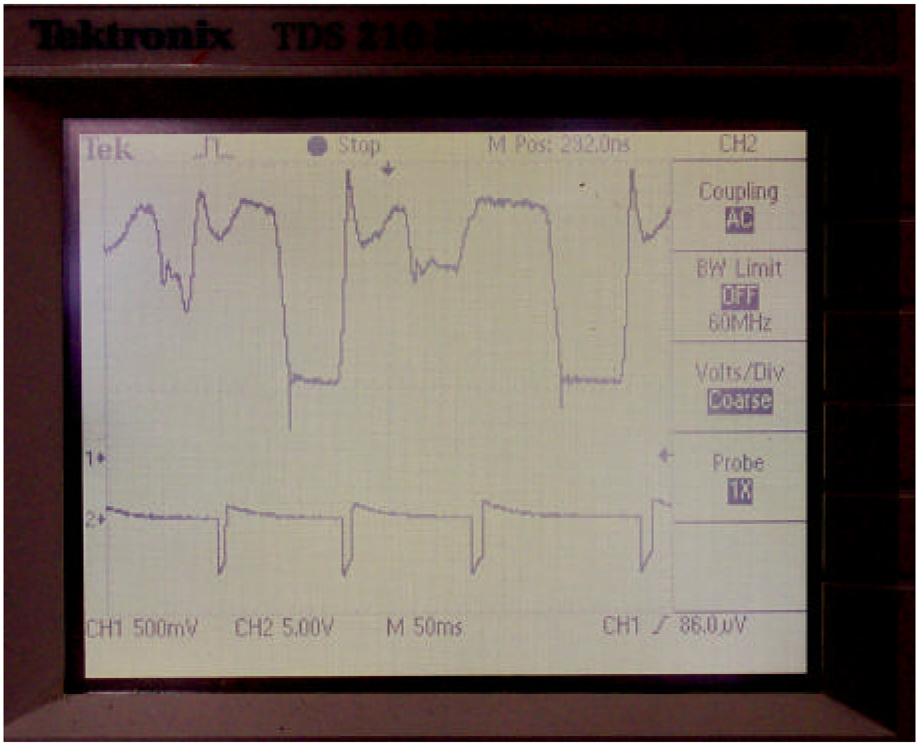


Fig 4.1: Output of linear potentiometer during test run of prototype engine. The bottom line is the signal from the cam sensor and the upper plot is a proportional representation of the valve motion. The deep valleys are when the solenoid opens the valve correctly. The shallow valleys are when the solenoid does not open the valve.

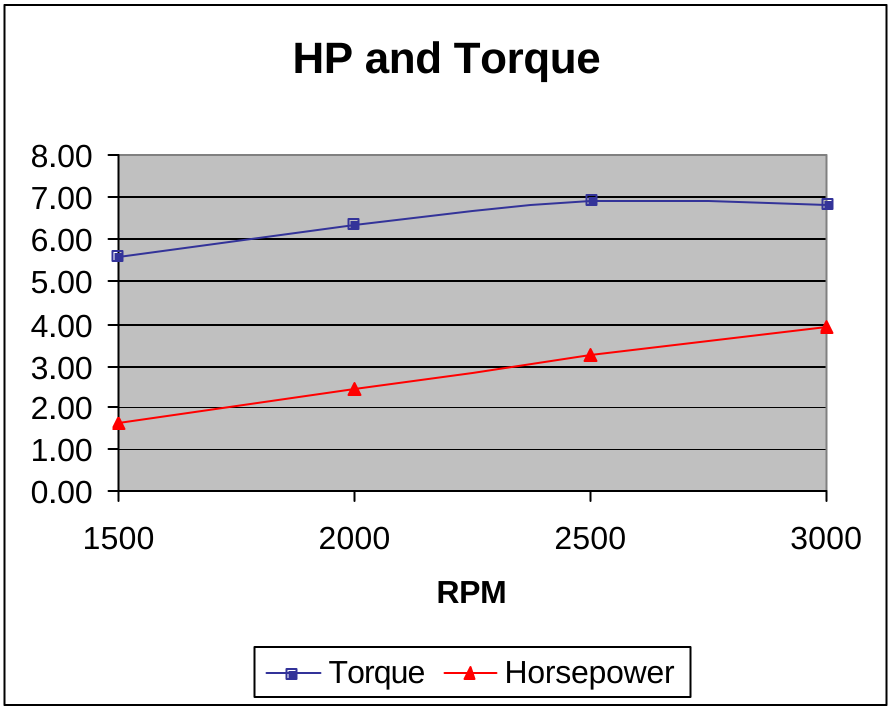


Fig 4.2: Horsepower and torque curves obtained from testing of stock GC160 engine.