Design And Analysis Of A Camless Valve Mechanism For I.C Engines Using Rotary Disc Valves

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Abstract: It is the object of the presented paper to provide an electromechanical rotary valve actuating system for opening and closing valves of an internal combustion engine, capable of separately controlling both the inlet and exhaust valve operations of each individual cylinder in a multi-cylinder engine. This indicates that only one valve will be required for each cylinder of the engine. Previously published versions of this concept require a separate valve for intake and exhaust in each cylinder. The system provides an alternative to the camshaft assembly, in an attempt to overcome the limitations and inadequacies inevitably posed by a fully mechanical system. The prototype development is approached in a theoretical manner, beginning with the conceptualization and design of a rotating disk with a notches and corresponding closure surfaces to open and close the flow path. The actuated disk and notch design is then refined and followed by the design of an inlet and exhaust manifold to correspond to the valve design, and the theorizing and design of a sealing gasket. The rotating speed of the valve is determined by a general idling speed, and can be varied to provide variable valve timing with the motor. The final assembly eliminates a majority of the moving parts currently used in camshaft systems, like the cam, camshaft, rocker arm, push rod and springs, and results in a significantly lighter valve actuation system. By eliminating the translatory motion of valves, the problem of valves slamming on the valve seats at high velocities is eliminated, thus greatly reducing engine wear.

Index Terms: Introduction, Disadvantages of Conventional Engines, Concept of Rotary Disc Valves, Calculations, Hardware Design, Material Considerations, Combustion Cycle Analysis, Assumptions

Introduction

The main problem is that a camshaft is very analog. What this means is that the valves will never just be open or closed, there will always be an in between stage that isn't as efficient as it can be. An ideal profile for a cam used in the cam shaft would be called a square cam profile, but there isn't really a practical way to do that with camshaft operated poppet valves. 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. Recognizing this compromise, automobile manufacturers have been attempting to provide vehicles capable of cylinder deactivation, variable valve timing (VVT), or variable camshaft timing (VCT). These new designs are mostly mechanical in nature. Although they do provide an increased level of sophistication, most are still limited to discrete valve timing changes over a limited range.

Disadvantages of cams (and subsequent advantages of presented design):

1. The conventional actuating systems include camshafts and link mechanisms added to the engine, which is necessarily <u>large in size, and consequently heavy</u>. The rotary valve system eliminates most of these elements, resulting in a lighter assembly that is easier to balance.
2. Since the camshafts and the link mechanisms are driven by the output shaft of the engine, the engine output power is partly consumed due to the frictional resistance produce when the camshafts and the link mechanisms are driven by the engine. As a result, the <u>effective engine output power is reduced</u>. The presented design uses an electromechanical motor to actuate the valve disk, and draws no power from the engine shaft.
3. The timing with which the intake and exhaust valves are opened and closed cannot be altered during operation of the engine. The valve opening and closing timing is preset such that the engine operates with high efficiency when it rotates at a predetermined speed. Therefore, the <u>engine output power and efficiency are lower when the engine rotates at a speed different from the predetermined speed.</u> A motor operated valve disk can be easily advanced or retarded according to engine RPM.
4. The valve operation, on account of the <u>elasticity of the system</u> and the <u>resulting vibrations</u>, is not very precise while accelerating or operating at high engine speeds.
5. The <u>operation is noisy</u> on account of various sliding surfaces and mechanical linkages.
6. <u>Greater maintenance</u> required due to more wear at more joints.

In view of the aforementioned problems, it is an object of the following paper to provide an electrically actuated valve for use in fuel admission systems which is both fast acting and highly reliable and at the same time has sufficient capacity for functioning in automobile engines. It is a related object to provide a valve which opens and closes rapidly with minimal delays. It is still another object to provide a valve which is compact, lightweight and economical. It is still another object to provide a valve which operates under fairly low gas supply pressures and which consumes little power in operation. The presented rotary valve system adds to existing systems of its kind in a number of ways. By incorporating both intake and exhaust capabilities into one valve, the system requires only one valve per engine cylinder, while providing ample surface area of opening for the passage of gas mixture at the same time. The valve is provided below the engine lining, not unlike poppet valve heads. This means that the pressure generated in the cylinder during compression and expansion press the valve against its seat and effectively serve to seal the cylinder. The valve system is capable of displaying truly variable valve timing (VVT) by simply controlling rotational speed through the motor. This means that the engine will give maximum output even at RPMs other than its predetermined RPM.

Prior Work on Rotary Valve Mechanisms

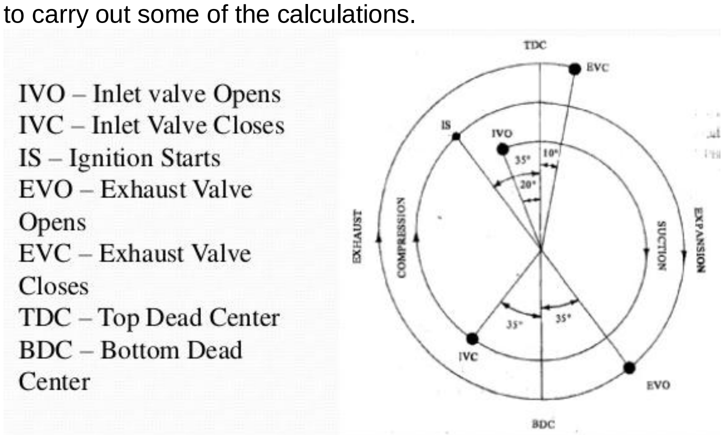
1. A rotary disc valve inlet system has been previously seen in the Kreidler 6 speed racing engine. Here the rotary valve is connected to the engine crank shaft and is rotating with the engine rpm. The valve uses a slot in its area to allow the inlet mixture to pass through which they refer to as the inter period.
2. Use of rotary valves has also been seen in other systems like the Coated Spherical Valve Rotary System. Several systems use rotary ball valves which although differs from our design as far as the valve type is concerned, however using a similar concept or principle of fuel admission into the combustion chamber.
3. A design partially similar to ours' is displayed by the PatRoVa rotary valve. It consists of a pair of vertically arranged oppositely facing fronts of disc valves which work on a similar rotary principle for the admission of fuel and passage of exhaust gases into and from the combustion chamber respectively.

Calculations

The calculations below are done taking an idling engine speed of 1000 RPM

The calculations will be shown below step by step categorically.

The following valve timing diagram was used as reference to carry out some of the calculations.



Speed of Rotary Valve

The crankshaft makes 1000 Revolutions in 1 minute

The crankshaft makes 1000 Revolutions in 60 seconds

Therefore, the crankshaft makes 2 Revolutions in T=120/1000=0.12 seconds

i.e. the crankshaft completes 1 full combustion cycle in 0.12 seconds

Now, for a rotary disc valve, the valve has to complete one cycle in 0.12 seconds

i.e. the rotary disc has to complete 1 Revolution in 0.12 s

Therefore, the required speed of the disc = 500 RPM

Time spent during the intake stroke

The crankshaft rotates for 235° out of the full 720° it rotates in 0.12 s

Therefore, the time spent during the intake stroke = (235/720)*0.12 = 0.0392 s

Time spent during the exhaust stroke

The crankshaft rotates for 225° out of the full 720° it rotates in 0.12 s

Therefore, the time spent during the intake stroke = (225/720)*0.12 = 0.0375 s

Time Spent during the Compression and Expansion

The crankshaft rotates for 290° out of the full 720° it rotates in 0.12 s

Therefore, the time spent during the compression and expansion stroke = (290/720)*0.12 = 0.04833 s

Time of overlap between initialization of the intake stroke and completion of the exhaust stroke

The crankshaft rotates for 30° out of the full 720° it rotates in 0.12 s.Therefore, the time spent during the mentioned overlap = (30/720)*0.12 = 0.005 s

Dimensions of Inlet and Exhaust Slots on the engine lining

The rotary valve comprises 360 ° which represents one combustion cycle. The crankshaft rotates 720 ° through one complete combustion cycle i.e. twice that rotated by the rotary valve essentially meaning that every angle represented on the rotary valve for any stroke is half of the angle through which the crankshaft rotates for the same stroke.

Thus, slot angle for the intake stroke = 235/2 = 117.5°

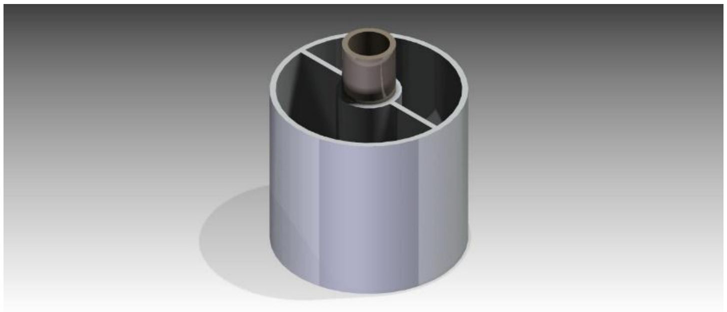
Similarly, slot angle for the exhaust stroke = 225/2 = 112.5°

Similarly, slot angle for the compression and expansion stroke = 290/2 = 145°

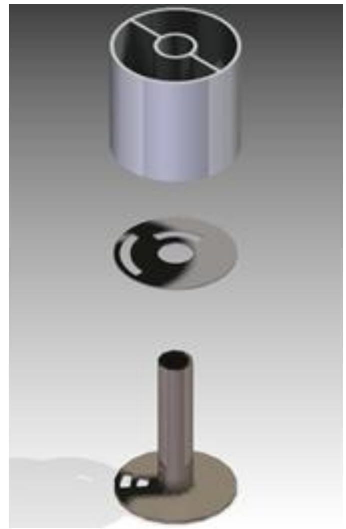
Similarly, slot angle represented for the valve overlap = 30/2 = 15°

Hardware Design

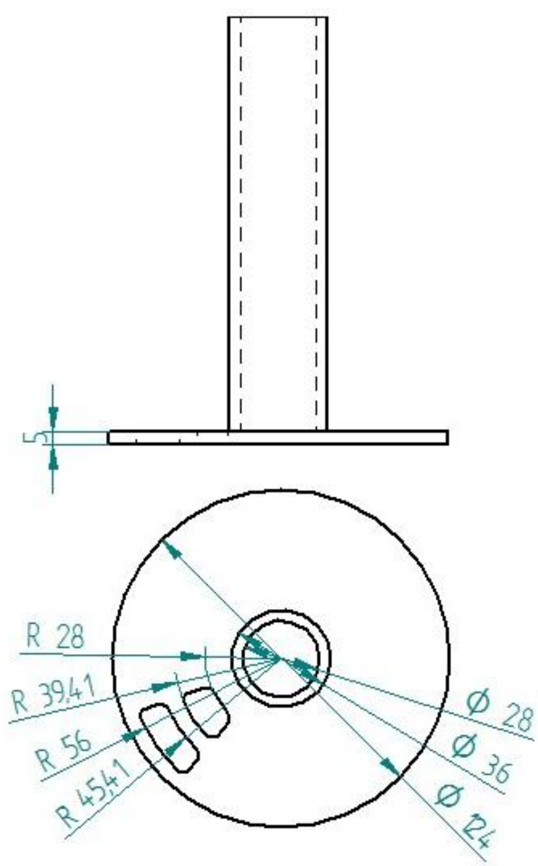
The basic design of the system consists of the following components: The rotating disk valve, attached to the DC motor which actuates it. The valve is provided with slots along the disk. They correspond with the openings on the valve cover in accordance with an ideal valve timing diagram during operation. A valve lining, provided with valve openings to allow passage of charge into the cylinder. The valve lining also serves to separate the intake and exhaust manifolds. It has been designed to be used as a separate valve support fixture for each cylinder, and facilitates both intake and exhaust actions as well. A gasket/sacrificial plate placed between the valve and lining prevents wear and tear of both components by slowly wearing itself down. The gasket material has been chosen in such a way that the action of the valve would not cause any wear on itself, but would wear the slightly softer gasket. It also serves to effectively seal the cylinder.

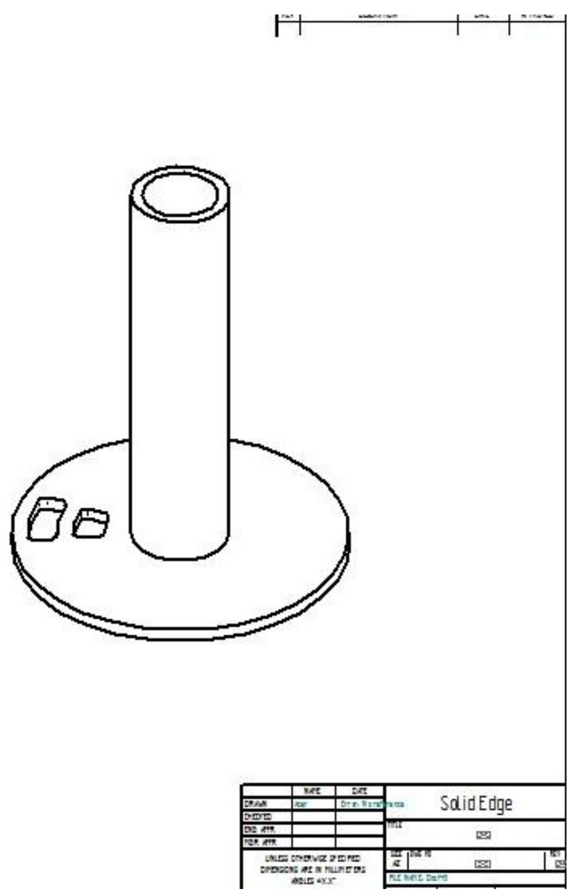


Exploded assembly



VALVE:
The design of the system began with the disk valve, and most components were designed around and on the basis of the valve. A draft showing Part Manufacturing Information (PMI) for the valve is given below:

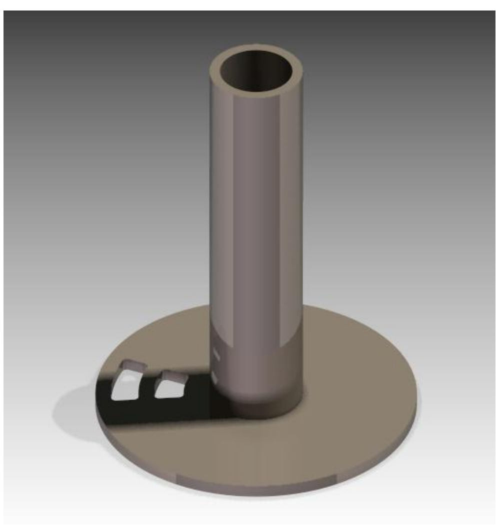




The working component of the valve, i.e., the rotating disk, was designed keeping in mind it's ability to incorporate both intake and exhaust cycles during operation. Thus, each cylinder requires only one valve for it's working. The flow path is opened and closed when the notches on the valve disk correspond to the openings on the lining during a controlled rotation. Nimonic 80a was assigned as the material to be used after careful consideration of the requirements and properties needed. Nimonic 80A alloy is a nickel-chromium alloy that is strengthened by the additions of titanium and aluminum. It has high tensile and creep-rupture properties at temperatures up to 815°C (1500°F).

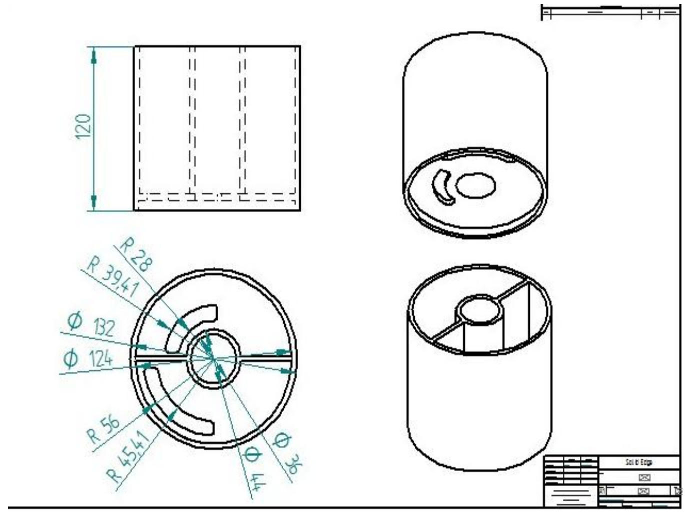
Properties and Advantages of Nimonic 80A

1. It has an ability to withstand very high temperatures and pressures.
2. Nimonic 80A alloy can be machined using conventional machining techniques used for iron-based alloys.
3. The alloy has low density and high tensile strength.
4. The alloy has good ductility, and can be readily formed using all conventional methods.
5. Nimonic 80A alloy can be welded using conventional welding techniques such as gas-tungsten arc welding, shielded metal-arc welding and submerged-arc welding.
6. Nimonic 80A alloy can be heat treated at 1079°C (1975°F) for 8h and air cooled.
7. The alloy can be forged at temperatures ranging between 982 to 1177°C (1800 to 2150°F).
8. Cold working of this alloy can be done using standard tooling.
9. The alloy can be annealed at 1079°C (1975°F) for 8 hours and air cooled.
10. The alloy can be hardened by cold working.

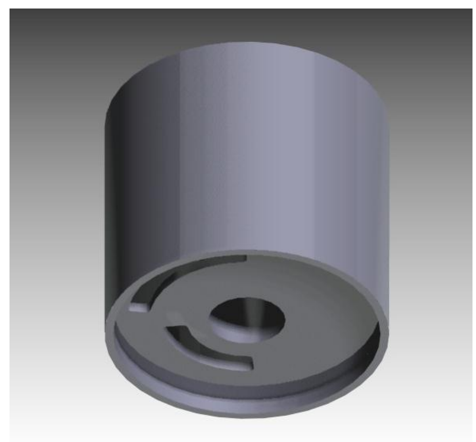


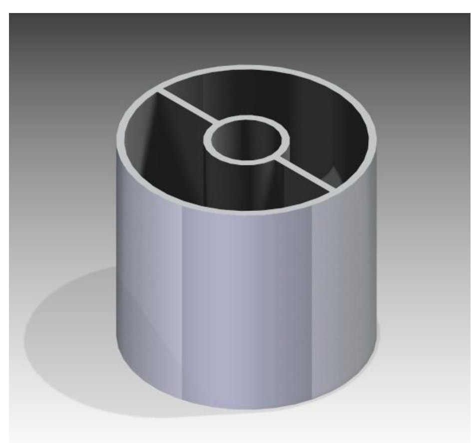
LINING:

The valve lining was designed to serve a number of purposes. The valve rotates in a concentric circular groove in the lining which is provided with opening notches to provide a flow path. The notches were designed and placed at specific angles to correspond with the ones on the valve disk according to a desired valve timing diagram. The intake/exhaust can be advanced or delayed by controlling the rotation speed of the valve in relation with the speed of the engine crank shaft.

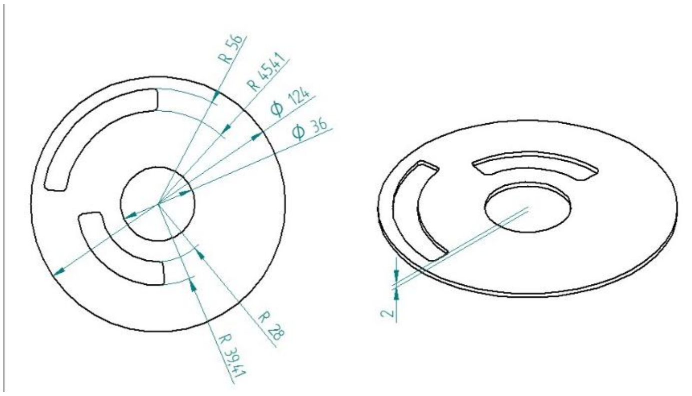


The lining also serves as a makeshift exhaust and intake manifold. The central rib separates the intake and exhaust sides and does not allow the incoming charge to mix with the exhaust gases. This ribbed design also imparts strength and stability to the assembly, minimizing vibrations and improving engine balance.





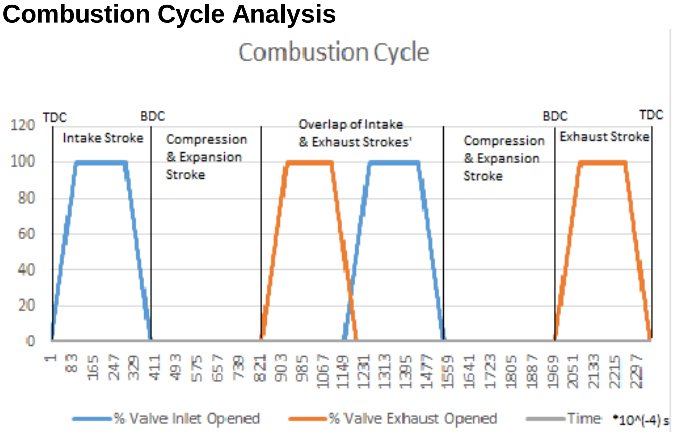
GASKET:



Material Considerations

Stainless steel 410 was chosen for the gasket material. Since the gasket is to serve as a sacrificial plate, the Brinell Hardness Number (BHN) of the plate was to be very slightly less than that of the valve to be protected. With the BHN of Nimonic 80A being 201 and that of Stainless Steel 410 being 170, this combination of materials proves to be theoretically ideal.

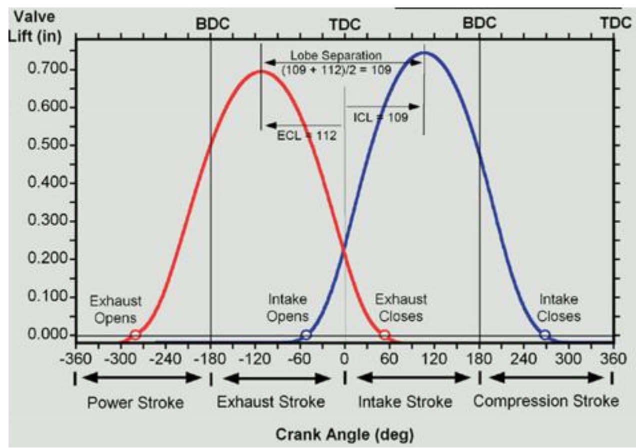
Combustion Cycle Analysis



The graph shown above represents the combustion cycle specific to our case using rotary disc valves which is analogically similar to a cam profile diagram for conventional engines where a graph of the valve lift against the crank angle is plotted. The vertical axis represents the percentage of the inlet valve and the exhaust valve opened in the intake and the exhaust stroke respectively. The horizontal axis represents time where the time period of 1 combustion cycle is 0.12 s where each unit time is 0.0001 seconds. The above graph shows two combustion cycles. As shown in the intake stroke the inlet valve gradually opens in 0.01 seconds, stays open for 0.0192 seconds and gradually closes in 0.01 seconds. Following this the compression and power stroke last for 0.0435 seconds. After this the exhaust valve gradually opens in 0.01 seconds, stays open for 0.0175 seconds and gradually closes in 0.01 seconds. Moreover, the overlap of the intake and the exhaust strokes has been shown where the overlap lasts for 0.05 seconds.

Comparison with Conventional engines

As mentioned before, for convention engines graphs of the valve lift are plotted against the crank angle. Here the maximum valve lift represents the fully opened state of the valve and the minimum valve lift represents the fully closed state. The crank angle represents the angle that the crank shaft has rotated through about its own axis where 720 ° of rotation represents one cycle. Such a graph has been shown below. In this graph one can clearly see that the inlet and exhaust valves open gradually, are completely open for a moment before they start closing and gradually close again. Now, for the rotary disc valve system designed, as one can see in the above graph the valve gradually opens, stays open for a while before it starts gradually closing again which is true for the intake as well as the exhaust stroke. One can clearly notice that the time for which the valves are fully opened are nearly twice the time they take to gradually open or gradually close. This is a major advantage which although theoretical, is nevertheless significant that has been achieved using rotary disc valves over conventional poppet valves.



Comparison with Ideal Engines

In an ideal engine, during the combustion cycle, the sequential opening and closing of poppet valves is supposed to instantaneous i.e. during intake stroke the inlet valve is supposed to open instantaneously, remain open for the entire time period dedicated to the intake stroke after which it must close instantaneously. The exhaust valve must follow the same process. Using rotary disc valves, in theory it has been shown that the time taken for the inlet and the exhaust valve to open or close is nearly half of the time period for which the valve is completely open. Thus, even though instantaneous movement of the valves is not possible as is desired ideally, nevertheless rotary disc valves furnish values much closer to the ideal ones as compared to conventional engines using poppet valves.

Assumptions

The following assumptions were made during the design process:-

1. The rotation of the rotary disc valve is actuated by a DC Motor fastened along its vertical axis. It is assumed that as soon as the motor is given the required power, it starts rotating at the required RPM almost instantaneously.
2. Another assumption that has been made is that the sacrificial plate used between the rotary disc valve and the engine lining which is made of stainless steel 410,

that also functions as a gasket, completely seals the combustion chamber from the engine manifold.

3. In this design the slots on the rotary disc corresponding to the inlet and the exhaust valves are open for a time period determined by valve timing diagrams for 4 stroke S.I Engines. However, the area available for the passage of the inlet mixture into the combustion chamber and the passage of the exhaust gasses out of the combustion chamber is lesser as compared to the area available for the same purpose in conventional engines using poppet valves. It has been assumed that since the passage of the inlet mixture or exhaust gases is determined by the pressure difference between the engine manifold and the combustion chamber, a reduction in the passage area available will automatically increase the speed of the passing mixtures thereby delivering the same volume of the mixture as done in conventional engines.
4. It has been assumed that the DC motor can deliver the required RPM constantly and accurately despite the friction the rotary valve will encounter on its surface while rotating against the engine lining.
5. It has been assumed that the materials that have been selected for the rotary valve and the sacrificial plate/ gasket after careful study, will successfully be resistant to very high temperatures occurring in the combustion chamber.
6. To calculate the speed of the dc motor, the slot angles required on the rotary valve as well as on the engine lining, a particular valve timing diagram has been taken as reference. It has been assumed that in this design the principles of the combustion cycle will not change. Thus here the focus has been laid on designing a better method for intake and exhaust of the inlet mixture and the exhaust gases respectively with the assumption that the time periods of the different strokes comprising the combustion cycle will remain unchanged.
7. This assumption concerns the sacrificial plate/metallic gasket being used in this design which has been placed between the rotary disc valve and the engine lining. It has been assumed that since the metallic gasket requires to be still, it can conveniently be press fitted and secured to the desired tightness.

Conclusion

The primary purpose of this paper was to introduce and elaborate a concept of rotary gate valves as a possibility in I.C. engines for automobiles. The goal was to conceptualize a valve mechanism that would not be dependent on a camshaft for its operation, thus eliminating the analogous nature of current cam based systems, and to enable a valve to have continuously variable valve timing, which could be controlled as easily as using a feedback from the speed of the engine to the valve motor. The paper theorizes the working of the valve as would be required for overcoming the difficulties posed by the current systems. With respect to the scope for further improvements to the concept, a few possibilities presented themselves while working on this project. In one embodiment, compressive pressure can be provided by springs located between the bottom plate of the valve housing and the rotating disc. The compressive pressure can be of such magnitude to compensate and/or overcome weight effects resulting from alignment of operation of the valve. For example, the valve can be employed in a variety of orientations with respect to the material flow path such as the valve can be operated suspended and orientated such that flow path is vertical. In a further embodiment, cooling can be incorporated into various dynamic components in the system to prevent damage to heat sensitive components.

References

[1] http://www.geocities.ws/lucfoekema/KreidlerV6.html

[2] http://www.douglas-self.com/MUSEUM/POWER/unusualICeng/RotaryValveIC/RotaryValveIC.htm#now

[3] http://www.pattakon.com/pattakonPatRoVa.htm