

59 The Rotating Cylinder Valve 4-Stroke Engine A Practical Alternative

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The Rotating Cylinder Valve (RCV) Engine is a novel 4 cycle engine that is a practical alternative to conventional 2 and 4 stroke designs, in particular for small capacity single cylinder applications. It is primarily intended to address applications where emissions legislation is forcing manufacturers to abandon the traditional carburetted 2 stroke. It has particular benefits for the moped/light motorcycle market.

The engine operates on a simple principle. The cylinder liner is rotated around the piston at half engine speed via a pair of bevel gears. A port in the side of this cylinder indexes with inlet and exhaust ports in the surrounding casing. This rotary valve serves the cylinder as the engine cycles through the conventional 4 stroke cycle.

The main technical issue that has been addressed is the design of a practical rotary valve seal. The RCV seal design provides a gas-tight compression seal, accommodates large thermal distortions, and takes up both production tolerance and longer term wear. The design is low cost, and simple to assemble and service. The rest of the components within the engine are conventional.

The RCV engine offers all the normal emissions advantages that a 4 stroke has over a conventional 2 stroke. It also has many benefits compared to a conventional poppet valve 4 stroke, in particular a predicted production cost comparable to a conventional 2 stroke.

The design has other significant technical benefits, including excellent thermal distribution, and good breathing characteristics. For moped applications the rear wheel power output of the engine will be competitive with current 2 stroke designs and exceeds the power output of typical small capacity poppet valve 4 stroke designs.

Keywords: Automotive General, Engine, Engine Component / Rotary Valve, Emissions, Four stroke, Single cylinder, Moped

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1. INTRODUCTION

The RCV Engine has been developed over the last few years as a compact low cost 4 cycle engine intended as a direct replacement for conventional small capacity 2 and 4 stroke designs over a wide variety of applications. Unlike many novel engine designs it is actually in production and has now been sold for use in aeromodelling applications for a number of years. Several thousand engines are now operating successfully around the world. In the field it has been proven to be a powerful and reliable design. This proven technology is now being

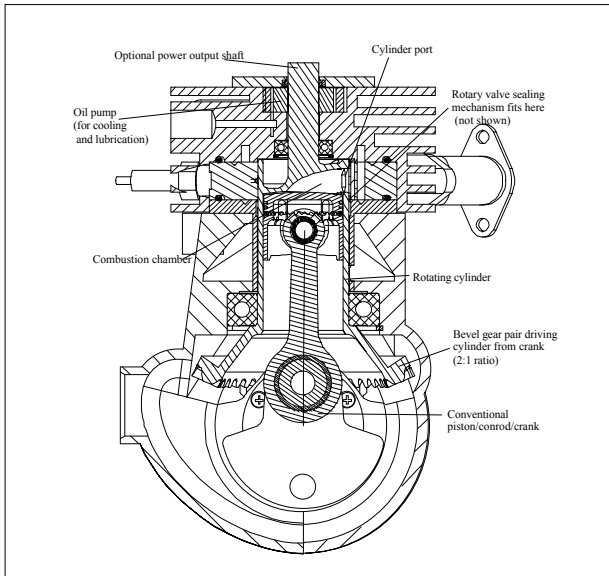
adapted to both light automotive and utility applications.

Principle of operation

(See figs 1 and 2)

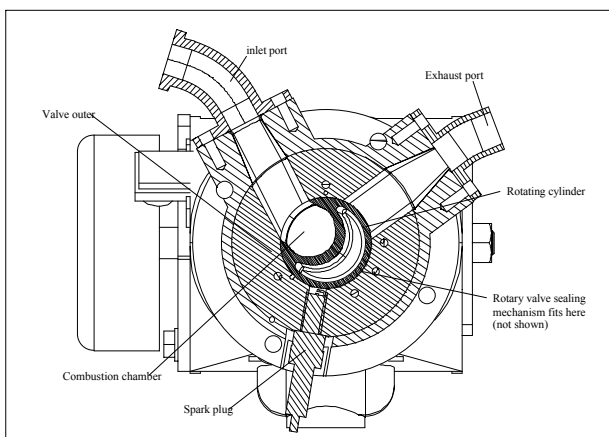
The RCV engine operates on a simple principle. The cylinder is mounted on bearings which enable it to rotate around the piston. A small bevel gear on the crank meshes with the larger bevel gear on the cylinder, the ratio being 2:1. As the piston reciprocates and the crank turns, the cylinder is rotated around the piston at half engine or cam speed.

Fig 1. RCV Engine Overall cross section



At the top end of the rotating cylinder there is a single port leading to the combustion chamber. This is surrounded by a fixed timing ring with three radial ports; inlet, ignition and exhaust. This simple rotary valve arrangement serves the combustion chamber as the engine cycles through the conventional 4-cycles: induction, compression, power and exhaust. The rotating cylinder is thus effectively combined with the rotary valve in a single component, hence the name RCV - Rotating Cylinder Valve.

Fig 2. RCV Engine cross section through valve area



On the moped implementation of the engine the power drive is taken from the rotating cylinder. Using this 2:1 geared down power output significantly reduces the power losses from the variator transmission unit, and also enables the engine to be

run at comparatively high RPM without overstressing the transmission.

On the moped engine an oil cooling system is employed. A pump installed on the output shaft of the rotating cylinder draws oil from the sump. This pump forces the oil through drillings around the ports and head and then around the outer surface of the rotating cylinder. The very even thermal distribution of the design eliminates hot-spots and simplifies the cooling system requirements.

Main engine components

The majority of the engine's components are conventional in design. In particular the RCV uses conventional components for the two most technically challenging areas of the internal combustion engine: sealing the combustion gases and withstanding the compression/reciprocation forces.

A completely conventional piston and cylinder are used for the main combustion seal. This is the most reliable component configuration that can maintain a good gas seal and tight lubrication control whilst withstanding the high sliding speeds and harsh thermal environment of the I.C. engine.

A conventional conrod and crank are used to withstand and transmit the combustion and reciprocation forces. Again these very high forces are best dealt with by this conventional component arrangement.

Technical issues to be addressed

The use of conventional components throughout the design means that reliability is not an issue for most of engine. There is some query over the affect of rotating the bore around the piston, however it seems likely that this may actually produce performance benefits. This is because, unlike a conventional engine, the piston and rings keep moving relative to the cylinder at all times, which results in a drop in friction and a resulting performance and durability benefit [1].

There is only one aspect of the RCV engine where there are major technical issues to be addressed. That is the design of the rotary valve.

Rotary Valve 4 Strokes. A Brief Design History.

The RCV Engine is in effect a rotary valve four stroke engine. Rotary valve four stroke engines have long been advocated as offering significant benefits compared to poppet valve designs. However none have ever made a significant impact on the market. This is for two main reasons.

Firstly the benefits of the various rotary valve designs implemented to date have been comparatively limited. For example the two most famous implementations, the Cross and Aspen designs, are as complex and bulky as poppet valve engines, and seem to offer little potential for cost

savings. Their only significant benefit over the poppet valve engine is improved detonation resistance due to the lack of a hot exhaust valve, a problem that has been overcome with improved fuels and detailed design.

In contrast the RCV engine offers far more significant benefits to the manufacturer [2][3]. In particular its production cost is much lower than a poppet valve, roughly equivalent to conventional carburetted 2 stroke. These and other benefits are analysed in greater detail below.

Secondly it has proven to be extremely difficult to design an effective four stroke rotary valve seal. This is due to the tight sealing tolerances the valve must maintain whilst operating with limited lubrication, large thermal stresses and high surface speeds. The Cross valve design was technically successful [2], but was not commercially exploited. RCV believe that this was because the comparatively bulky implementation negated the limited operational benefits. The Aspen design was not technically successful, requiring unacceptably high levels of lubrication to avoid wear or seizure [2]. RCV believe that this is due to the unavoidably large seal pressurisation area of the design (this is explained below).

In contrast the RCV engine incorporates a compact, low cost and effective rotary valve seal. This design can achieve acceptable durability with minimal blow-by and low lubrication levels. The operation of the seal and the simple design principles and calculations that it involves are summarised below.

2. RCV ROTARY VALVE SEAL DESIGN

RCV have found that the design of the rotary valve seal must obey the following four basic principles:-

1/ The valve must have an active sprung sealing mechanism. This is for the simple reason that thermal movements within an engine are an order of magnitude greater than the clearances that must be maintained to provide a reasonable combustion seal. Typically engine components will expand and distort by many tens or even hundreds of microns due to thermal effects, whereas to ensure an adequate combustion seal clearances must be no more than a few microns. A sprung sealing mechanism is thus required to maintain these small sealing clearances whilst allowing for comparatively large thermal distortions. The seal movement will also allow for production tolerances and wear.

The RCV valve seal mechanism has a seal component on the rotating cylinder consisting of a frame surrounding the outer edge of the cylinder port. This seal is sprung against the outer fixed valve

ring to form the main compression seal. This seal component is referred to as the **sliding seal**.

2/ The spring that forces the sliding seal against the inner surface of the valve must also seal the gas path around the back of the sealing element. The interface where the sliding seal bears upon the spring must form a continuous static seal around the cylinder port. A conventional spring cannot be used as gas would leak through the spring and around the rear of the seal. The spring element is referred to as the **seal spring** because it acts as both a static seal and a spring.

3/ The seal must be arranged in such a way that the cylinder pressure augments the seal spring pressure. That is the pressure in the cylinder must force the sliding seal against the outer fixed valve ring to improve the seal. This principle is followed by all successful conventional sealing components e.g. piston rings, poppet valves etc. The effective area of the seal upon which the combustion pressure acts to increase the sealing force is referred to as the **seal pressurisation area**.

Although it is essential for the cylinder pressure to augment the static sealing pressure, it is necessary to limit the seal pressurisation area to ensure this additional sealing force does not become excessive. If the seal pressurisation area is too large the additional force exerted on the seal by the cylinder pressure will cause excessive friction in the valve. This will cause a significant loss in performance and unacceptable wear. The calculation to work out an acceptable seal pressurisation area is simple, and is outlined below.

On the Aspen valve design the valve occupies the entire inner surface of the cylinder head, which means that the effective seal pressurisation area is the same as the bore area. RCV believe that this is the main drawback of the design as it leads to very high seal pressurisation forces and consequential high frictional losses and wear.

4/ Whilst a mechanism obeying the above principles will adequately seal the combustion gas, provision must also be made to provide a secondary sprung sealing mechanism for the inlet and exhaust ports. It this is not done oil control and inlet manifold pressure stability will be poor.

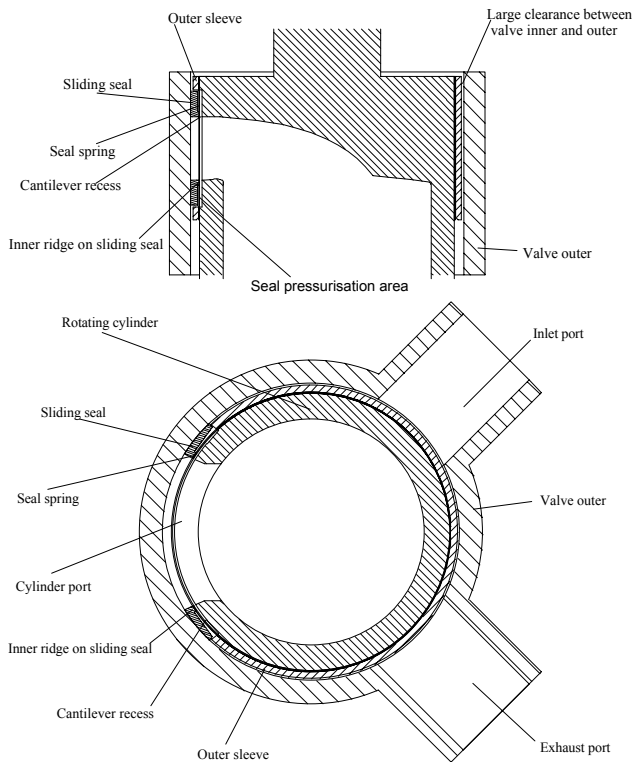
Basic valve design

The basic valve design provides a compression seal only and does not contain provision for a secondary sprung seal for the inlet and exhaust ports.

The most challenging aspect of the valve design is the seal spring. This must both provide a spring force to force the sliding seal against the valve outer, and also seal the gas path around the rear of the sliding seal. The design RCV are currently using is referred to as a clamped cantilever spring. This is a

thin flat shim clamped around the outside of the port with a cantilevered overhang upon which the inner edge of the sliding seal bears. Fig 3 shows a cross section of a simple implementation of the clamped cantilever spring design. Fig 3 is shown in an expanded form in Appendix A.

Fig 3. Cross section of simple valve seal



On this version the shim forming the seal spring is wrapped completely around the cylinder and held in place with the outer sleeve. The seal spring incorporates a hole of similar dimensions to the cylinder port which is aligned with the cylinder port. Around the cylinder port there is a shallow recess over which the seal spring protrudes forming a continuous cantilevered overhang around the cylinder port. When the sliding seal is in place in the aperture in the outer sleeve the internal ridge on its inner edge rests on the inner edge of the seal spring. With the seal spring in its relaxed state the sliding seal will stand slightly proud of the outside surface of the outer sleeve. When the assembly is placed within the valve outer ring the sliding seal will be pushed down and bend the seal spring downwards into the cantilever recess. The seal spring thus acts as a spring forcing the sliding seal outwards against the inside surface of the valve, and also forms a static seal with the inner edge of the sliding seal. Gas pressure acting on the inside surface of the seal spring will augment the spring pressure to improve the seal for the short periods during the four stroke cycle when combustion pressures are high. Fig 4 shows a photograph of the simple seal components. On the left there is a rear view of the

sliding seal showing the ridge around its inner edge. In the centre the inner and outer sleeves showing the aperture which accepts the sliding seal and into which the cantilevered section of the seal spring protrudes. On the right there is a front view of the sliding seal.

Fig 4. Simple valve seal. Sliding seal rear view, inner and outer sleeves assembled, sliding seal front view.



The materials employed are conventional. The seal spring is made from a standard stainless steel shim material. The sliding seal is a bronze alloy. The valve outer ring upon which the sliding seal runs (not shown) is lined with a thin cast iron sleeve. This combination of materials has been found to be completely reliable and totally resistant to pickup and catastrophic failure. It is felt that at this stage of development it is necessary to get the valve to work reasonably well on conventional materials, so that more exotic materials and surface treatments can be held in reserve for more extreme performance requirements.

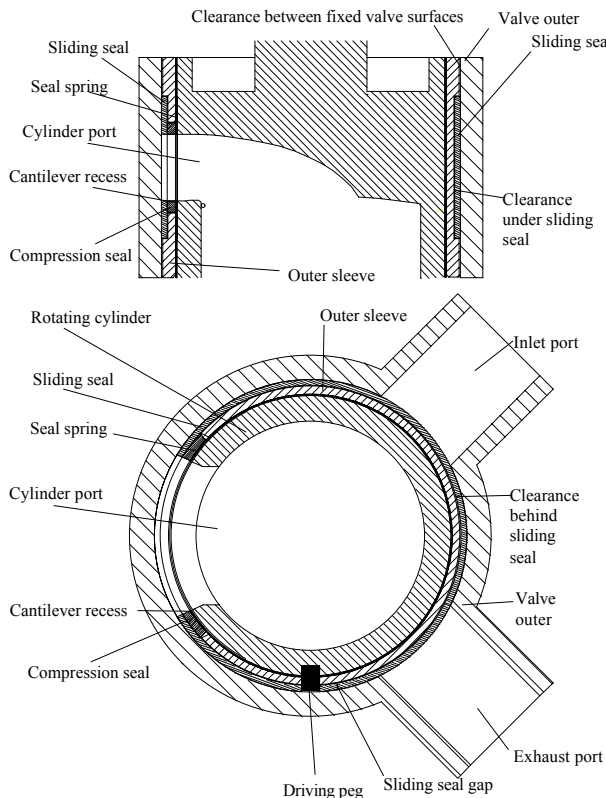
This simple seal design functions very well in terms of sealing compression, but due to the comparatively high clearance that must be maintained between the fixed outer surface of the outer sleeve and the inner surface of the rotary valve there is some gas transaction between the crankcase cavity and the inlet/exhaust ports resulting in lubricant contamination of the combustion stream. During testing this resulted in occasional oil contamination of the plug and a smoky exhaust. As a result an improved design of seal was developed, the sprung expanding ring valve seal design.

Sprung expanding ring valve seal design

The simple cantilevered spring valve seal design only actively seals the cylinder port. The sprung expanding ring valve seal design uses a sprung expanding ring around the full inner circumference of the valve to provide a secondary sprung seal mechanism for the exhaust and inlet ports as well as the primary compression seal.

A simplified cross section of the sprung expanding ring valve seal is shown in fig 5. Views of the main components are shown in figs 6-8. Fig 5 is shown in expanded form in Appendix B.

Fig 5. Cross section of sprung expanding ring valve seal



The sprung expanding ring sliding seal operates on the same principle as a piston ring. As manufactured it is a larger diameter than the valve outer into which it will be fitted but is gapped so that it can be compressed and fitted into the valve outer. The sprung expanding ring sliding seal is dimensioned so that when it is fitted into the valve outer the gap closes up to around 0.3mm. This allows for thermal expansion of the ring, and is precisely equivalent to setting the correct ring gap on a piston ring.

The sprung expanding ring sliding seal has two other features, a large rectangular hole for the cylinder port, and a second small hole for a driving peg. The peg radially locates the sliding seal to line the rectangular hole in the seal up with the cylinder port, and also drives the seal round as the cylinder rotates.

The seal spring is constructed in an identical manner to the simple seal design above using a flat shim and a cantilever recess around the cylinder port.

In operation the sprung expanding ring sliding seal is performing two separate sealing functions.

Firstly it provides a primary seal around the cylinder port to seal the combustion gas. The sealing mechanism is almost identical to the simple seal

design above, the only difference being that a separate component, the compression seal, is used to transmit the spring force from the seal spring to the sliding seal. The compression seal is equivalent in function to the small ridge around the inner edge of the sliding seal on the simple seal design above. It is manufactured as a separate component to simplify manufacture of the sprung expanding ring sliding seal.

The sprung expanding ring sliding seal also provides secondary seal for the inlet and exhaust ports. This function is carried out by the sprung expanding ring expanding to run close against the entire inner circumference of the fixed valve outer.

This sprung expanding sliding seal around the complete inner circumference of the rotary valve provides a well defined boundary between the inlet/cylinder/exhaust stream, and the engine's internal cavities. This improves oil control and provides more stable idle/low throttle operation by ensuring better control of the inlet manifold vacuum.

Fig 6 shows the sprung expanding ring and compression seal removed from the rotating cylinder.

Fig 6. Sprung expanding ring valve sliding seal and compression seal



Fig 7 shows the seal spring and outer sleeve assembled onto the cylinder with the sliding seal and compression seal removed. The edge of the seal spring cantilevered overhang can just be seen around the edge of the cylinder port. The peg which locates and drives the sliding seal can also be seen. The compression seal sits within the aperture around the cylinder port and bears on the edge of the seal spring. The sprung expanding ring sliding seal sits between the upper and lower lips of the valve outer sleeve.

Fig 7. Sprung expanding ring valve seal with sliding seal and compression seal removed.



Fig 8 shows the valve fully assembled. When assembled there is a significant clearance gap between the inner surface of the sliding seal and valve outer sleeve. The sliding seal is only in contact with the driving peg and the compression seal. This ensures that the sliding seal is free to float at all times so that when assembled into the engine it can run snug against the outer valve ring regardless of the thermal distortions and movements of the cylinder.

Fig 8. Sprung expanding ring valve seal fully assembled



One further benefit of this design is that the sprung expanding ring sliding seal retains all the seal components in their correct positions when the valve outer is removed.

The materials are the same as for the simple valve except the sliding seal and valve outer materials are swapped over i.e. the sliding seal is cast iron and the valve outer is lined with a bronze alloy. This is to give the sliding seal better spring characteristics.

In tests the sprung expanding ring seal has performed extremely well. It is simple to assemble,

requiring no set up or adjustment to produce good compression. The engine always starts well, runs well, and develops good power, with little or no blow-by gas from the valve. Initial dyno test results are included below.

Seal frictional losses calculations

During development a version of the original simple seal using a larger area seal spring was prototyped. This larger seal spring has a longer cantilever, which reduces the static spring pressure, although it increases the seal pressurisation area. In tests although the seal gave excellent compression it had a significantly reduced torque/power output (around 5% down).

It was suspected that the reduction in power was due to the increased seal pressurisation area causing increase frictional losses during compression. The larger area seal spring had an effective seal pressurisation area of 5.5cm^2 compared to the original seal design which had a effective seal pressurisation area of 2cm^2 .

To calculate the valve frictional losses a spreadsheet was drawn up. The spreadsheet contains a simple cylinder pressure v crank angle simulation. It calculates the instantaneous retarding torque for every 10 degree segment of the complete 720 degree four stroke cycle, and averages this to give an overall loss in torque due to the valve seal.

The calculation is carried out as follows.

At any one point in the cycle the seal force (the force pushing the sliding seal against the fixed valve outer) is the sum of the static seal spring force and the force due to the cylinder pressure acting on the seal pressurisation area thus:-

$$\begin{aligned} \text{seal force} = & \\ & \text{static seal spring force} \\ & + (\text{seal pressurisation area} * \text{cylinder pressure}) \end{aligned}$$

The instantaneous retarding force caused by this seal force at any one point in the cycle is simply the seal force multiplied by the coefficient of friction of the valve materials thus:-

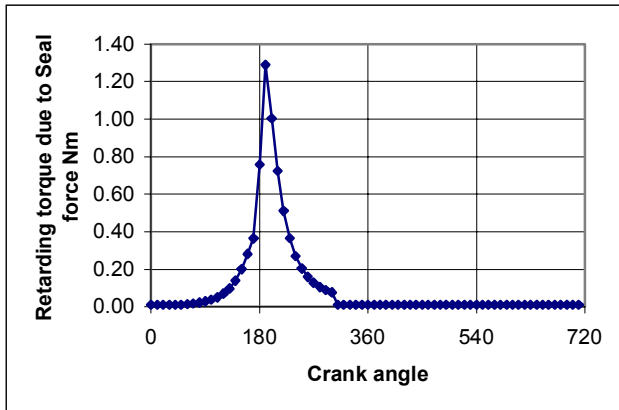
$$\begin{aligned} \text{retarding force} = & \\ & \text{seal force} \\ & * \text{valve materials sliding coefficient of friction} \end{aligned}$$

The instantaneous retarding torque is simply this force multiplied by the effective torque moment, in this case the valve radius.

$$\begin{aligned} \text{retarding torque} = & \\ & \text{retarding force} \\ & * \text{valve outer diameter}/2 \end{aligned}$$

A typical example of how this retarding torque varies with crank angle is shown in fig 9.

Fig 9. Retarding torque due to seal force v crank angle



The above graph is for a static spring force of 10N, a seal pressurisation area of 2cm² and a coefficient of friction of 0.1, which is the best that would normally be achieved for lightly lubricated smooth sliding surfaces.

The spreadsheet averages this instantaneous retarding torque over the 720 degree cycle to give an overall retarding torque. For the example above the average retarding torque is 0.1Nm representing approximately a 4% loss.

Fig 10 below contains a table of results showing % torque loss for various seal pressurisation areas and static spring forces.

Fig 10. Predicted torque loss v seal pressurisation area and static spring force.

		Seal pressurisation area cm2		
		1.0	2.0	5.0
Spring	10	2.1%	3.9%	9.9%
	20	2.6%	4.3%	10.3%
	50	3.8%	5.6%	11.6%

The spreadsheet predicts a loss in torque/power of around 4% for the original smaller seal, and 10% for the larger area seal. This matches well the actual loss in power observed with the larger area seal.

The valve loss spreadsheet also shows that static spring pressure is not the major factor in determining power loss:- the static seal pressure can be comparatively high without causing significant loss in torque/power. It is the extra pressure applied to the seal during compression that needs to be controlled to limit losses.

The spreadsheet shows that in general for the 49cc engine to limit seal drag losses to a reasonable amount the effective seal pressurisation area should be around 1 cm² or less. As a result the latest version of the seal design has been adjusted to give an effective seal pressurisation area of around 1cm² resulting in a further small power/torque improvement. Losses from this version of the valve are calculated to be around 2%, which compares favourably to small engine conventional poppet valve train loss of around 4-6%. It should also be noted that losses in the RCV rotary valve will decrease at lower throttle settings due to the lower cylinder pressures, whereas poppet valve losses remain roughly constant, becoming more significant at lower throttle settings.

Valve durability and lubrication

RCV have yet to carry out formal life testing of the valve, but it is felt there should not be any significant problems achieving the typical lifetimes required for small engine applications. Estimates of lifetime gathered from testing to date have been very promising with the valve components showing little measurable wear after many hours of running. Moreover the fact that the seal is a sprung mechanism means that very significant wear can be accommodated in the seal before any loss in sealing performance occurs.

There have been no catastrophic failures of the sprung expanding ring valve seal. In fact the very first set of prototype components manufactured are still in use for testing, again indicating that the design potentially has good reliability.

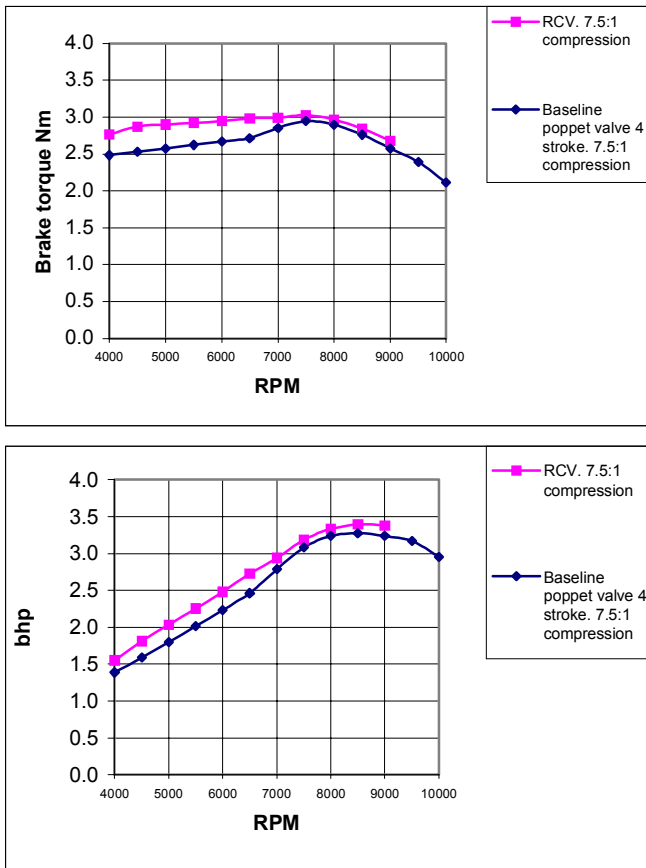
The valve seal is currently lubricated using oil pre-mixed with the fuel (50:1 ratio). This is done purely because it is a straightforward method of gauging the lubrication requirement, and will shortly be replaced with a simple metered feed from the oil pump. It is felt that lubrication of the valve will not produce a significant degradation in emissions performance. The best evidence for this is the good emissions performance of direct injection 2 strokes. The valve employed on a directly injected 2 stroke, i.e. the piston, is in many ways similar to the rotary valve on the RCV. A two stroke piston is a sliding valve with similar surface speeds to the RCV rotary valve and has to cope with the same harsh thermal environment. The fact that adequate lubrication of the DI 2 stroke piston does not appear to significantly degrade its emissions performance indicates that lubrication of the RCV valve will not be a significant technical issue.

As mentioned above the valve currently uses conventional materials, cast iron running on a bronze alloy. This material combination appears to give good durability with low levels of lubrication. More exotic materials and treatments are thus available in reserve to obtain further increase in lifetime if required.

Initial power test results.

Fig 11 shows the torque/power curves obtained from the first generation engine.

Fig 11. Torque and power curves of initial prototype compared to 4 stroke poppet valve



Development work has until recently concentrated on valve seal development and reliability with little emphasis on actual performance. The prototype engine currently has a restricted port size and low compression combustion chamber. Even so the initial power curves are promising. Initial peak power is 3.40bhp at 8500RPM.

All torque and power figures are corrected for standard temperature and pressure. Also shown are the calculated torque/power output curves for a typical poppet valve with the same compression ratio [2]. It can be seen that compared to the poppet valve the RCV shows a significant increase in torque of around 10% at lower RPM. RCV believe that this may be due to a combination of the reduction in valve train losses, and reduced friction from the rotating cylinder, although this has yet to be categorically proven.

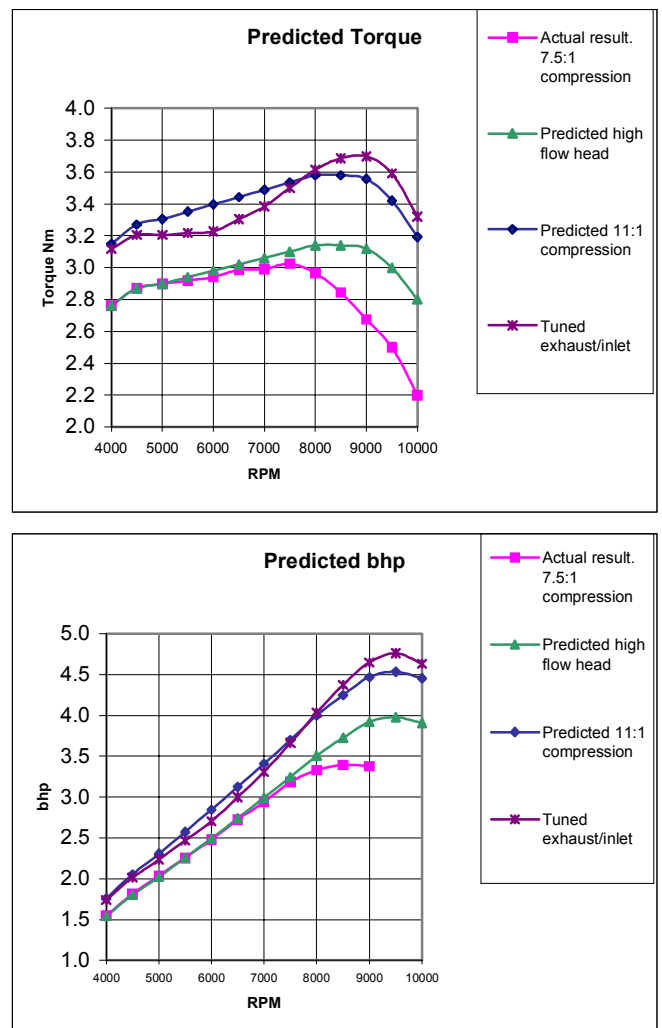
At higher RPM the torque advantage disappears. This may well be due to the restricted breathing of the first generation engine.

A high compression high flow version of the engine, with compression ratio of 10:1 and the inlet area and port size increased by 25% is already under construction and should be tested within the next month. Still higher compression ratios and inlet areas are readily possible and will be prototyped within the coming year. Predicted torque/power curves for the improved flow/compression RCV engine are discussed below.

Predicted torque and power curves for improved versions of RCV engine.

Fig 12 shows predicted torque and power curves for improved versions of the RCV engine starting from the baseline of the initial experimentally obtained power curve.

Fig 12. Predicted torque and power curves for high flow high compression RCV engine



The first improved curve shows the effect of a higher flow head. The current inlet port area and port size can be readily increased by a factor of 25%. This is conservatively assumed to move the maximum brake torque point up the power curve by 1000RPM to 8500RPM.

The second improved curve shows the effect of a higher compression (11:1) head. The current engine has a compression ratio of 7.5:1, therefore the affect of increasing the compression to 11:1 will be to increase the torque by around 14% across the operating range of the engine.

The third improved curve shows the effect of mild inlet/exhaust tuning. This is a very approximate estimate which simply puts a +/-5% ripple on the previous curve, with the peak designed to occur at the peak power point.

The effect of the above modifications is an engine with a peak power output of 4.75bhp @ 9500RPM. This is a very competitive power output level for a 49cc four stroke design. Combined with the efficiency savings in the transmission produced by the geared down engine output (see below) this should achieve on the road moped performance comparable with a standard 49cc 2 stroke.

The modifications to increase the port area by 25% are comparatively conservative, and it is easy to outline a port scheme with 50% greater area than the current prototype. This radical breathing concept is outlined in the benefits section below. This could shift the MBT point still higher up the RPM range producing an RCV engine with even greater bhp. Moreover because the output shaft is geared down 2:1 the engine can be run at these higher speeds without overstressing the transmission.

3. BENEFITS OF THE RCV DESIGN [1][2][4]

Production benefits

- **Up to 40% lower manufacturing cost compared to poppet valve 4-stroke or DI 2 stroke.**

The reduced component count and simplified construction of the RCV provide significant reduction in manufacturing costs compared to a conventional poppet valve 4 stroke. Independent cost assessments [2] put the cost close to that of a conventional carburetted 2 stroke, and it is believed that ultimately the cost could match that of a conventional 2 stroke. Note that this cost estimate is for the complete moped engine/transmission unit where cost reductions in the transmission, oil pump, casings and inlet tract effectively pay for the bevel gear pair and extra bearings.

- **Lower capital investment.**

The use of conventional components means that the capital investment required to switch production from a conventional 2 or 4 stroke to the RCV design is considerably reduced. In particular the piston, conrod, crankshaft and crankcases are manufacturable by the same plant. The more novel

components, the cylinder, gear pair and valve seal, are completely conventional in terms of the manufacturing techniques required.

Technical benefits.

- **Good thermal distribution**

The RCV has very even thermal distribution. All moving components are exposed to both inlet stream and exhaust stream in more or less equal measure. Moreover the rotation of the various components relative to one another means that heat energy is spread very evenly throughout the engine. In particular the RCV design does not have an exhaust valve, normally the hottest part of a conventional poppet valve 4 stroke. This potentially enables very high compression ratios to be run without detonation with consequent benefits in terms of torque, power output and fuel efficiency.

In practice the RCV engine runs cool, and can be run straight up to full throttle from cold without any fear of seizure or other adverse affects. Seizures and other thermally related failures are virtually unknown.

The oil cooling system currently employed, where oil is pumped through channels in the fixed outer valve, appears to be very effective. In the future a more radical direct cooling option will be prototyped. In this version oil will be pumped through the space between the inner surface of the sprung expanding ring seal and the outer surface of the rotating cylinder. This enables direct cooling of the majority of the outer surface of the rotating cylinder.

It is these good thermal characteristics which differentiate the RCV design from many other unconventional engine designs, in particular the Wankel engine.

- **Large port area.**

The valve area of the RCV design can match and even exceed the port area of a 4 valve head. Moreover the port is completely open and not impeded by the head of the valve as is the case with a poppet design.

The angular width of the port on a rotary valve is largely determined by the external diameter of the valve. The RCV rotary valve external diameter is maximised, being equal to the bore + the seal thickness. The height of the port is largely determined by the combustion chamber shape and configuration. Ultimately the RCV combustion chamber and piston can be arranged to give a height around 30-50% of the stroke. The combination of these two maximised dimensions leads to very large port areas. This in turn means good BMEP figures can be maintained to high RPM giving high bhp/litre performance.

The inlet port size is largely independent of bore/stroke ratio. It is not therefore necessary to adopt the radically over-square bore stroke ratios seen on some high performance engines.

- **Reduced friction**

The lack of valve train losses and rotating cylinder means that engine frictional losses should be reduced. Although this has yet to be categorically proven estimates of full throttle efficiency gains of between 5% and 10% are reasonable, with higher gains at part throttle [3].

- **No reciprocating valve gear**

The lack of conventional reciprocating valve gear means the mechanical limit for engine RPM is set by the piston/conrod/crank assembly alone. Combined with the large inlet port area this enables very high performance versions of the RCV to be produced.

- **Compact combustion chamber**

The RCV engine meets all the broad guidelines for efficient combustion chamber design i.e. a compact shape with the ignition point in a near ideal position for a swirling mixture.

The combustion chamber is offset from the centre of the cylinder bringing the bulk of the cylinder charge close to the ignition source. The inlet port is angled to induce swirl in the inlet charge. The ignition point is in the ideal position on the outside of this swirl.

- **4 stroke Lifetime**

Being a four stroke design the engine should have a longer lifetime than a 2 stroke. This is generally due to the more reliable lubrication, sealed bottom end, and absence of ports in the bore [1].

Application/operational benefits

- **Optional 2:1 geared down output.**

On the RCV engine power can either be taken from the crank in the conventional manner, or alternatively it can be taken from the rotating cylinder which is rotating at half engine speed.

The 2:1 reduction on the rotating cylinder power output is particularly important for moped applications. Taking the power output from the rotating cylinder enables the variator and clutch to be run at half engine speed, reducing the losses that occur within these components. Independent assessments indicate that this will result in an effective increase in rear wheel power of around 10%.

The 2:1 output also enables the RCV engine to be run at a higher crank RPM than a conventional engine. The higher RPM coupled with the good breathing characteristics of the engine allows a higher power output to be generated.

- **Small package size.**

An engine based on RCV technology is very much smaller in size than a conventional 4 stroke engine. This is due to the lack of a cylinder head. Typically an RCV engine would be 100 – 150mm lower than the equivalent OHC design. The lack of external

plumbing also makes the engine ideal for many hand held applications.

- **Optional low cost balance shaft**

On the RCV a counter-rotating balance shaft can be installed opposite the crankshaft meshing with the other side of the main cylinder bevel gear. This gives the RCV engine near perfect primary balance. This configuration not only reduces the cost/size impact of the balance shaft, but also places it in a near ideal position for improving the balance of the engine.

This is particularly important on single cylinder applications where vibration must be minimised, in particular hand held tools, and larger capacity single cylinder motorbikes.

Reliability Benefits

- **Uses conventional components**

As already stated unlike many new engine designs the RCV uses tried and trusted conventional components for the two most technically challenging areas of the internal combustion engine: sealing the combustion gases and withstanding the compression/reciprocation forces.

- **Elimination of reliability weakspots**

Some of the major maintenance and reliability weakspots of current engine designs are not present on the RCV.

There are no valve clearances to shim or adjust. This both reduces production line setup times/costs, and simplifies the maintenance schedule of the engine.

There is no cam belt to break or change. This is a major weakspot on current engines as failure to replace the belt at the required intervals can lead to major failures.

There is no cylinder head joint to warp or leak.

There is little external plumbing and no external “soft” components (hoses etc) which will degrade with time and whose failure will halt the engine.

- **Low maintenance**

Apart from standard oil and plug changes, no other routine maintenance should be required by an RCV engine for its entire working life.

4. SUMMARY OF THE POTENTIAL BENEFITS OF THE RCV DESIGN FOR MOPED APPLICATION.

- Simple low cost construction minimises cost of switch from 2 stroke to 4 stroke.
- Rear wheel power output competitive with 2 stroke.
- 2:1 output gearing reduces speed of transmission reducing losses in clutch and variator.

- Compact shape minimises package size and eliminates forward pointing cylinder. Allows radical styling options to be investigated.
- Lower maintenance than 4 stroke, greater durability than 2 stroke.
- Optional integral balance shaft ensures near perfect primary balance with minimal weight/size/cost penalty.

CONCLUSIONS

1. The RCV engine is a practical alternative to more conventional designs for small engine applications.
2. The RCV offers significant benefits over conventional designs. In particular it has the emissions performance and durability of a 4 stroke engine, with the effective power output and cost of a 2 stroke. It is therefore particularly suitable for applications where emissions legislation is forcing manufacturers to abandon the carburetted 2 stroke.
3. The RCV is a proven design. It is already being used in the field in significant numbers, and is achieving consistently good results on the dynamometer.
4. Most of the engine's components are conventional in nature and do not carry any technical risk. The one significant technical issue, the design of the rotary valve, has been successfully addressed.

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REFERENCES

- [1] Ricardo Consulting Engineers Limited, "RCV Engine Assessment", July 2001.
- [2] RCV Engines Limited, "Briefing Manual – Description And Analysis Of RCV Engine Technology", www.rcvengines.com, October 2001
- [3] The University of Texas at Austin; Dardalis, D, "Rotating Liner Engine – UT Austin Graduate Patents Process For Saving Diesel Engine

Fuels", On Campus, April 26, 2001 - VOL. 28, NO. 06

- [4] Dr Garner, Colin "Brief Appraisal Of The RCV Engine For Its Application To Motor Scooters", Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University Consultants Ltd, March 2001

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Below is a short description of acronyms, abbreviations and other words with special definitions which have been used in this paper

- BMEP:** Brake Mean Effective Power
Cylinder Port: Aperture in rotating cylinder that admits gas to and from rotating cylinder.
DI: Direct Injection
MBT: Maximum Brake Torque
RCV: Rotating Cylinder Valve
Seal Pressurisation Area: The area of the seal upon which the cylinder pressure acts to increase the sealing force.
Seal Spring: Component behind sliding seal that forces sliding seal outwards to form main compression seal, and also forms static seal with rear of sliding seal.
Sliding Seal: Component that slides against inner surface of rotary valve to form main compression seal and secondary inlet/exhaust seal.

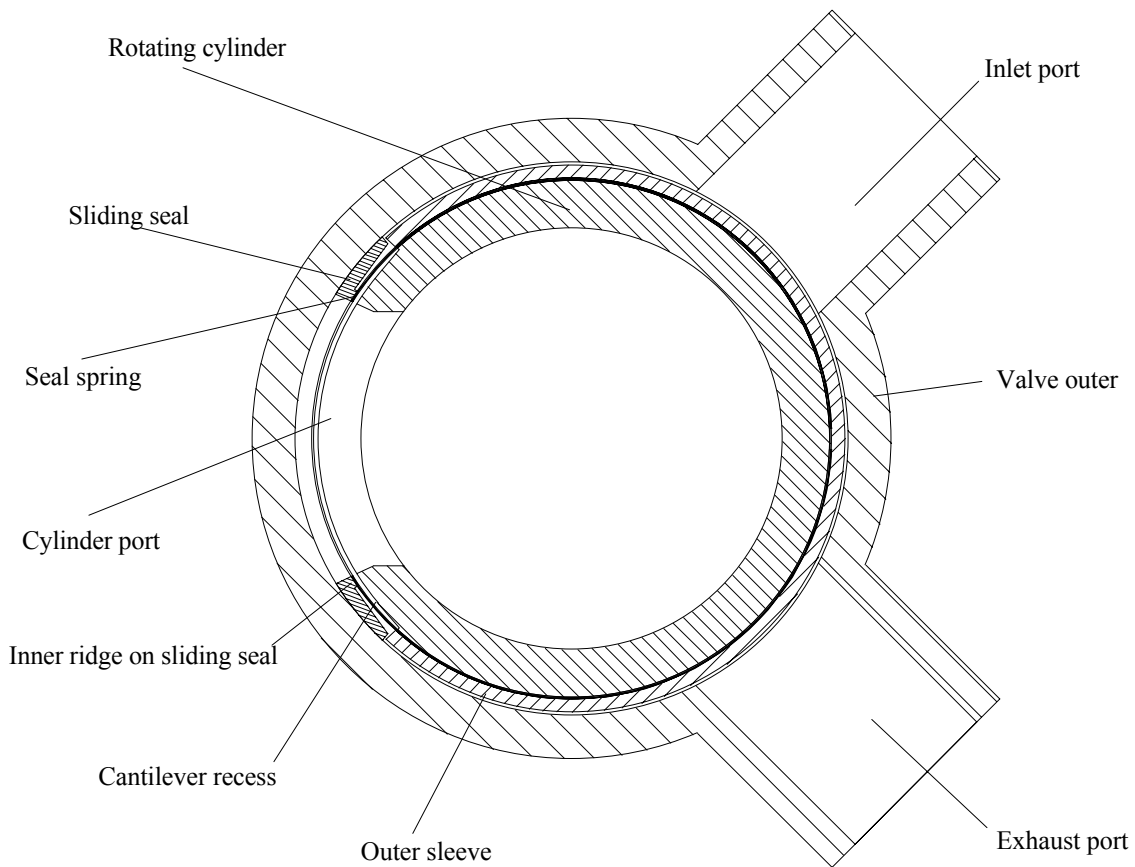
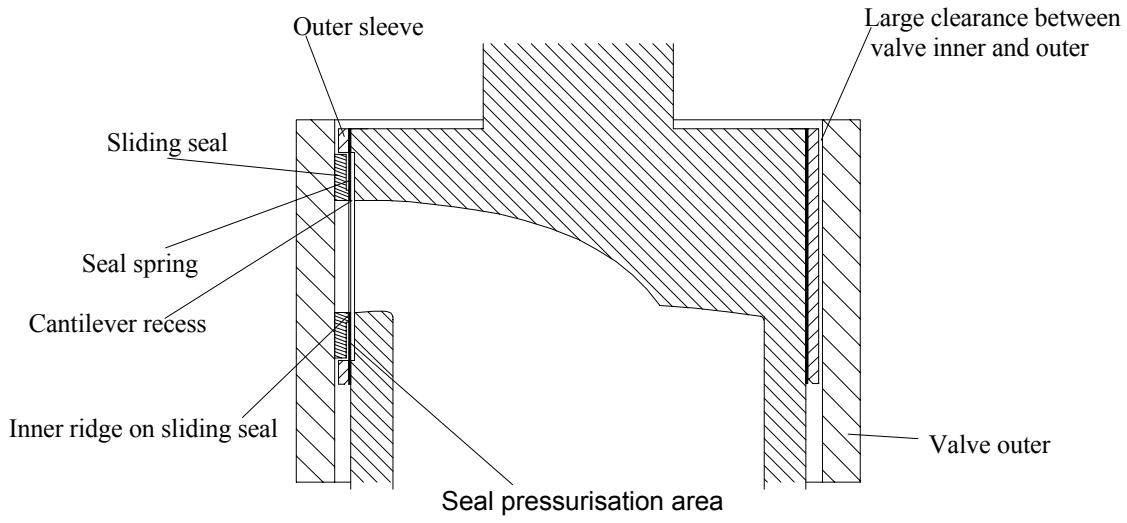
APPENDIX

- Appendix A** Full page Fig 3. Cross section of simple valve seal.
Appendix B Full page Fig 5. Cross section of sprung expanding ring valve seal.

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APPENDIX A - FIG 3. CROSS SECTION OF SIMPLE VALVE SEAL.



APPENDIX B – FIG 5. CROSS SECTION OF SPRUNG EXPANDING RING VALVE SEAL

