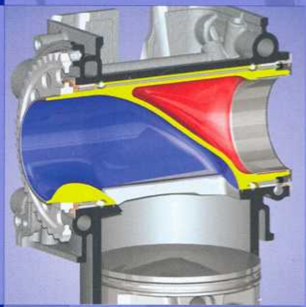
AutoTechnology

International Magazine for Engineering, Production and Management

special 2007

www.auto-technology.com

Magazine of FISITA - the world body for automotive engineers



Engine Technology
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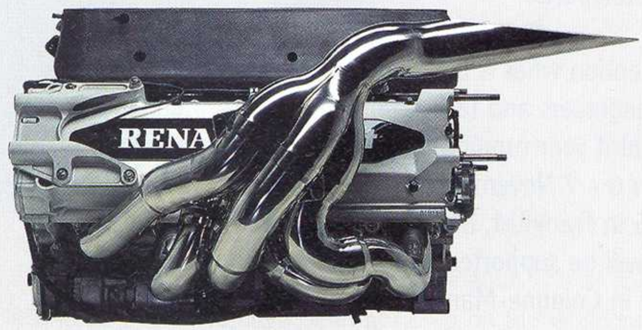

29 *In 2006, some of the greatest changes to occur in F1 for many years will see teams competing with completely redesigned engines. The tight envelope imposed upon designers requires more accurate analysis methods to understand, at a fundamental level, the subtle design changes required to win races, and suggests some approaches that may make the difference.*

The Bishop Rotary Valve

by Tony Wallis, Bishop Innovation

To demonstrate the credibility of Bishop Innovation's new rotary valve technology it joined forces with Mercedes-Ilmor to develop the technology for use on their V10 Formula One engine only to have its strategy destroyed by a change in engine regulations.

10% power advantage and improved durability

By the early 1990s Bishop Innovation had completed the initial development of its promising new rotary valve concept for IC engines and was looking for a way to further develop the technology. The automotive industry, having observed a succession of failed attempts spanning the last century, no longer believed the rotary valve concept was mechanically viable. It chose Formula One (F1), as the criteria for success was well matched to inherent advantages offered by the rotary valve. Further, a successful public demonstration of this technology in the extreme operating conditions of F1 provided a mechanism to address the industry's prejudice.

In 1997 Bishop started working with Ilmor Engineering (later Mercedes-Ilmor) to develop their rotary valve technology for F1 engines. The initial development was carried out on 300cc single cylinder bottom ends supplied by Ilmor at Bishop's premises in Sydney Australia. Bishop was responsible for the cylinder head design, development and demonstration of the required durability and performance. By late 2000 back to back testing with the poppet valve single cylinder engine demonstrated a 10% power advantage and improved durability. In 2002 the first V10 engines using this technology were built and tested exhaustively. A completely new V10 engine was designed and manufactured in 2003. Testing of these engines was prematurely terminated when the FIA announced changes to Article 5.1.5 of the engine regulations late in 2004 with the specific purpose of banning this rotary valve technology.

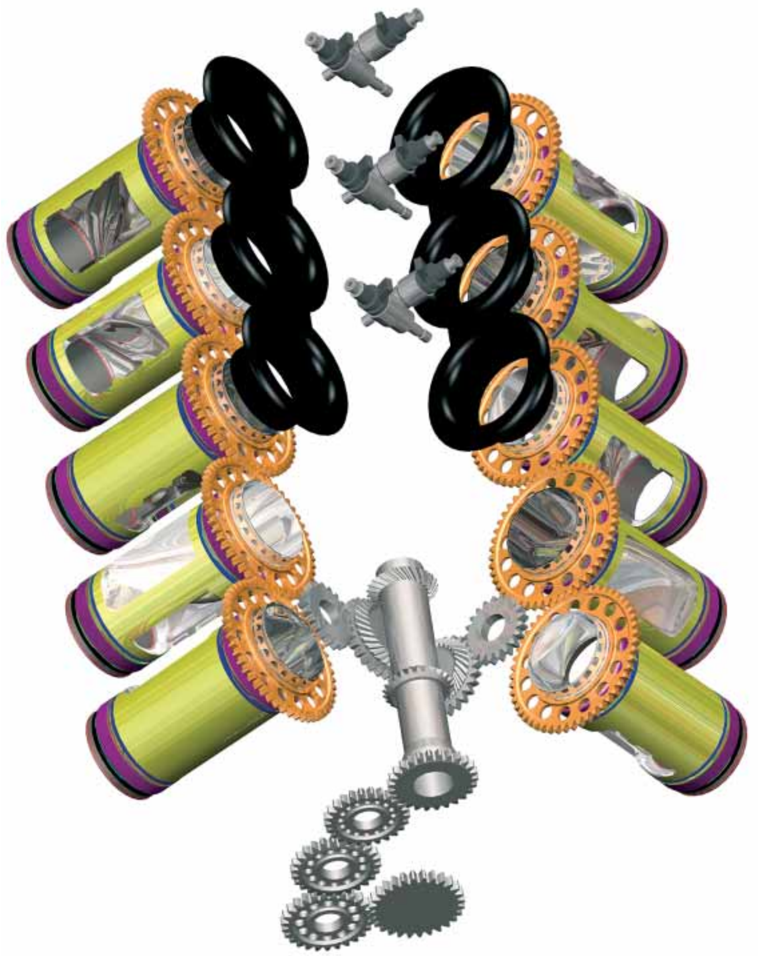

Figure 1: Valve drive train and inlet tract arrangement on V10 engine.

The Technology

The F1 rotary valve assembly is shown in Figure 2. The Bishop Rotary Valve (BRV) is an axial flow rotating valve incorporating both the inlet and exhaust port in the same valve. There is one valve per cylinder positioned with its axis perpendicular to that of the crankshaft. The steel valve is supported in two shell type needle roller bearings that ensure the valve's stepped centre portion always runs with a small radial clearance to the housing. The outside diameter of the valve's centre portion and the bearings are similar, allowing the valve assembly to be housed in a stepless bore. Face seals located at each end of the valve's centre portion prevent cooling and lubrication oil entering the centre portion and the cylinder. At the exhaust end a carbon face seal keeps the oil and

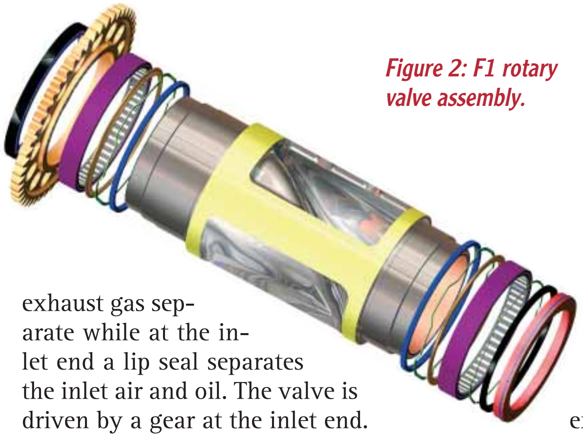

Figure 2: F1 rotary valve assembly.

exhaust gas separate while at the inlet end a lip seal separates the inlet air and oil. The valve is driven by a gear at the inlet end.

The outside diameter of the valve generally lies in the range 0.67 - 0.74 that of the cylinder bore diameter allowing it to be fitted to engines with conventional cylinder bore spacings.

The valve rotates at half engine speed and eliminates the inertia induced forces that have plagued the development of reciprocating poppet valve mechanisms since the invention of the IC engine. It is this feature that has inspired numerous inventors over the last century to chance their hand at developing rotary valve engines. These developments have generally failed due to a combination of problems involving gas sealing, oil sealing, excessive friction and seizure caused by thermal and mechanical distortion of the valve.

As a portion of the rotary valve's periphery is periodically exposed to the combustion process it is inevitable that thermal and mechanical distortion of the valve will occur. Bishop focused on finding a solution that would allow this small but inevitable distortion to be accommodated. In arrangements where both the inlet and exhaust port are in the same valve, a satisfactory solution is complicated by the requirement to prevent leakage between these ports. A typical previous approach was to use a stationary split sleeve located around and lightly preloaded against the valve's periphery. In such arrangements it was very difficult to create an even distribution of oil between the valve surface and the sleeve. This, combined with the sleeves poor ability to accommodate local distortion, resulted in high friction and seizure.

In the BRV arrangement the small radial clearance between the valve's periphery and its housing is designed to ensure that any thermal or mechanically induced distortion of the valve is accommodated without the valve's periphery ever touching its housing. Provided the radial clearance is kept small it provides sufficient flow resistance to prevent significant flow of gases between the exhaust and inlet port. In applications where this is not the case Bishop has developed additional technology to control these flows. This approach was immediately successful and allowed the early development to proceed without seizure, friction or lubrication problems.

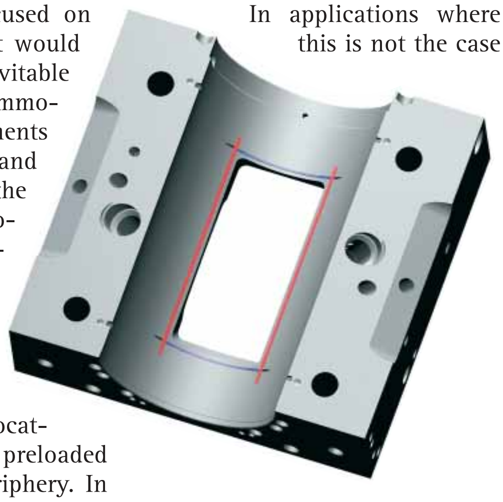

Figure 3: Gas sealing arrangement.

The gas sealing arrangement is shown in Figure 3. It consists of 2 axial seals and 2 circumferential seals located adjacent the window, housed in slots in the cylinder head and preloaded against the periphery of the valve. These seals function in a similar manner to piston rings. Unlike the piston ring they are subjected to a constant sliding velocity with no reversal of direction throughout the cycle. This arrangement allows the use of very long windows, an essential requirement if the breathing potential of this concept is to be achieved. Window length determines the opening and closing rate of the valve and the fully open flow area. The opening and closing rates on modern F1 engines are very high and can only be matched by rotary valves which have window

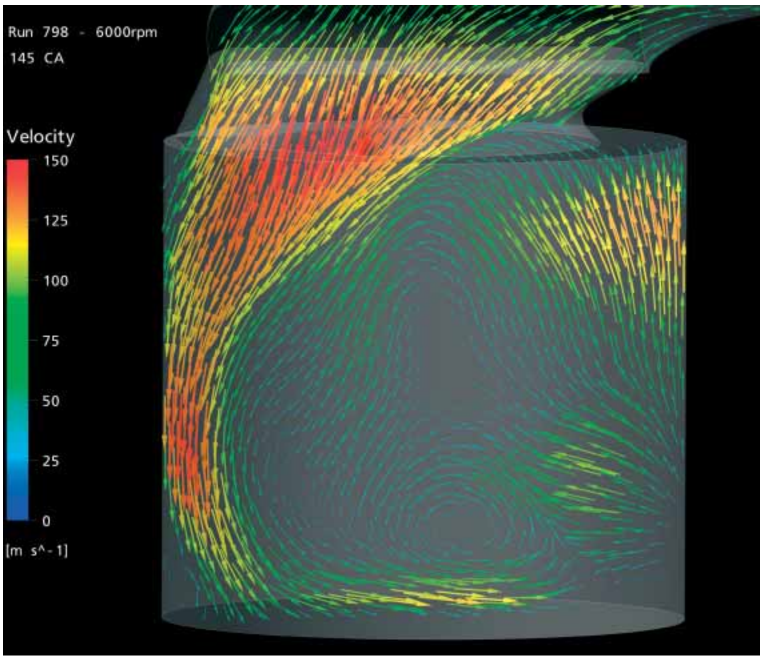

Figure 4: CFD of production valve showing oblique flow through window and the start of tumble flow.

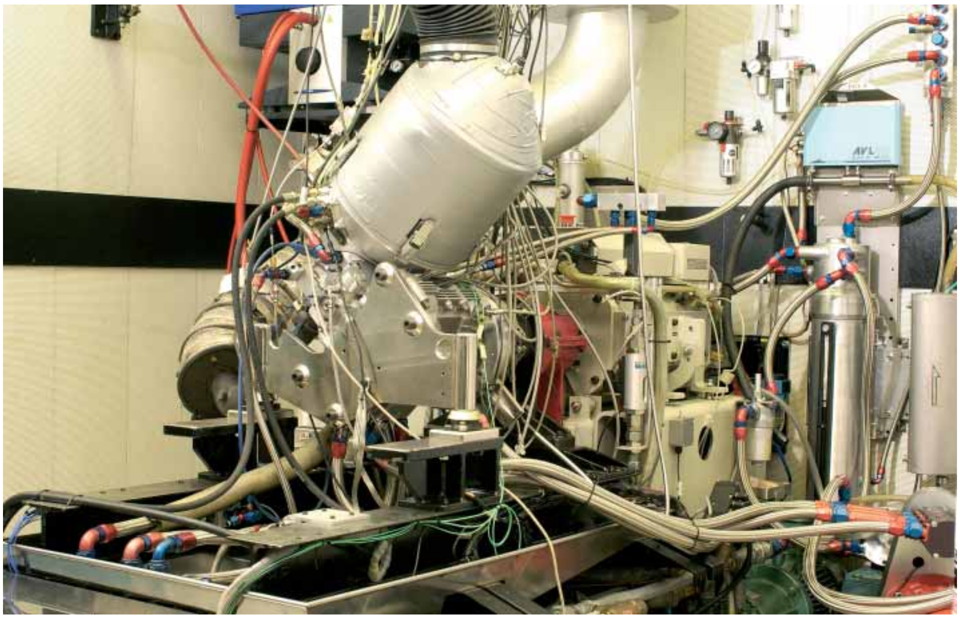

Figure 5: Single Cylinder BRV engine on Bishop's 18,500 rpm dynamometer.

In axial flow rotary valves the air flow through most of the inlet tract is parallel to the window and perpendicular to the cylinder axis

lengths greater than 0.77 that of the cylinder bore diameter.

In axial flow rotary valves the air flow through most of the inlet tract is parallel to the window and perpendicular to the cylinder axis. This is quite unlike poppet valve arrangements and often leads their designers to incorrectly conclude that the rotary valve cannot breathe as well as the poppet valve.

In the Bishop design much of the air passes obliquely through the window. This is well illustrated in the CFD image shown in Figure 4. The air flow adjacent the port floor is turned through approximately 35° before it passes through the window while the air adjacent the port roof is turned through approximately 90°. As all the flow must at some stage be turned parallel to the cylinder axis the remaining rotation takes place in the cylinder itself. While this oblique flow suppresses the discharge coefficient the unobstructed flow path through the window tends to compensate. While the discharge coefficient (based on the window area at the combustion chamber surface) of early valve designs was only 0.54 (fully open valve) steady development has seen this improved to 0.72 on current F1 heads.

This oblique flow through the window is responsible for one of the rotary valves most useful attributes - its strong in-cylinder tumble flow. The tumble ratio on engines with near square bore/stroke ratios is typically twice that reported for similar 4 valve engines. Unlike the poppet valve this high tumble flow is generated without any loss of volumetric efficiency (VE) and is responsible for very fast burn rates observed. Production based engines built in the early 1990's had ignition timing of 15°, or less than half that of the best four valve engines.

The Testing

Extensive back to back testing demonstrated that the peak volumetric efficiency was the same for both poppet and rotary valve engines. The difference, if any, occurs in the engine speed at which the VE first starts to fall when optimum length tracts are fitted. The 10% power advantage observed on the single cylinder BRV engines in 2000, was in part a result of the rotary valve being able to maintain peak VE to higher speeds than the poppet valve. By 2004 the poppet valve and rotary valve engines were both able to maintain peak VE to engine speeds greater than 18,000 rpm.

During the course of the BRV development valve diameters between 58 and 70 mm have been manufactured and tested. Flow testing has demonstrated that the peak flow capacity of these valves increases linearly with valve diameter. By selecting a suitable valve diameter, peak VE can be achieved at what ever speed is required. CFD simulations suggest that valves could be produced that enable peak VE to be maintained at speeds up to 25,000 rpm. Further increases are unlikely as it is difficult to make the inlet tract short enough to achieve the correct wave action.

Whilst the rotary valve engine has demonstrated breathing capacity that is at least equivalent to the best F1 poppet valve engines, it has the huge advantage that it does this without the dramatic reduction in life that occurs with F1 poppet valve heads. As inertia induced loads in the valve train are absent in the rotary valve, the forces that destroy the poppet valve heads are also absent. Further the mechanical and gas loads seen by the valve are essentially independent of speed. The only issue affecting durability that changes with engine speed is the peripheral speed of the sealing elements and the bearings. As the peripheral speed of the valve over the sealing elements is approximately 80% that of the maximum F1 piston ring velocity, this is of little concern. In production poppet valve engines, engine life considerations require changes that greatly curtail their breathing capacity from the level achieved in F1. This is clearly not the case with the rotary valve and Bishop's research suggests a production rotary valve has a breathing capacity up to 45% greater than that observed on current 4 valve production engines.

The numerous BRV engines tested over the last 18 years have all demonstrated remarkable resistance to engine knock. In the early 1990s engines with conventional bore/stroke ratios ran compression ratios as high as 15:1 on unleaded 93 octane pump petrol. The F1 single cylinder engine ran compression ratios as high as 17:1 using standard F1 fuels before settling on 15.3:1 as optimum. No evidence of knock has ever been observed and this is thought to arise from an absence of any hot surfaces in the combustion chamber (the valve surface moves continuously through the combustion chamber) and the very fast combustion rates. Bishop anticipates rotary valve production engines could run compression ratios as high as 15:1.

Formula One Rotary Valve Engine

A schematic showing details of the valve drive train and positioning of inlet tracts and injectors for the V10 engine is shown in Figure 1.

A section through a single cylinder version of the F1 cylinder head assembly is shown in Figure 6. The cylinder liner is cast integral with the cylinder head thus eliminating the need for a head gasket (one of the weakest elements on a poppet valve F1 engine) and for cored water passages in the cast cylinder blocks. In the cylinder head there is no requirement for the complex water gallery cores typically found in the poppet valve head. Apart from some simple water transfer galleries the water cooling galleries are all drilled.

The 3 litre V10 F1 rotary valve engine weighed in at less than 80kg, making it easily the lightest V10 F1 engine ever built. It weighed approximately 16kg less than the equivalent poppet valve engine with which it shared a similar bottom end. A significant contributor to this weight reduction is the integral liner and head. The presence of a head gasket requires very rigid heads and blocks and large stud loads to maintain adequate pressure on the gasket. Not only can smaller studs and less stiff housings be used but the geometry of the integral liner and head itself greatly increases the stiffness of the head.

Figure 6: Section through Rotary Valve Cylinder Head Assembly.

As most of the weight saving came from the top half of the engine there was also a considerable reduction in the engine's centre of gravity (C of G). The cylinder head height was reduced by approximately 50mm producing a strikingly compact engine. This was a significant achievement as F1 engines are already remarkably compact compared to their production cousins. Figure 7 shows a comparison between a Mercedes 230 SLK cylinder head and a single cylinder version of a rotary valve cylinder head suitable for use on this size engine. The height saving is 150mm. Bishop estimates that, compared to current 4 valve engines, weight savings up to 4kg/cylinder could be achieved on production BRV engines.

On the power front both the rotary and poppet valve engines were designed for the same maximum speed and both engines produced near identical power outputs despite far greater resources being devoted to the development of the poppet valve engine. From a F1 perspective the rotary valve had the potential to increase power faster as it could increase its breathing capacity by merely increasing the valve diameter and unlike the poppet valve it had no inertia issues preventing its operation at higher speeds.

With advantages in height, weight, C of G, elimination of inertia loads, breathing and greater durability Bishop is confident that, had the technology not been banned, it would have become the technology of choice for racing engines.

This technology has potential in production applications

This technology has considerable potential in production applications where it has the additional advantages of fast combustion, low valve drive torque and high compression ratio capability. Bishop anticipated that demonstration in F1 would provide the impetus for the considerable further development required to bring this technology to production. Regrettably F1 has abandoned its long standing raison d'être to "improve the breed" and replaced it with "protection of the status quo".

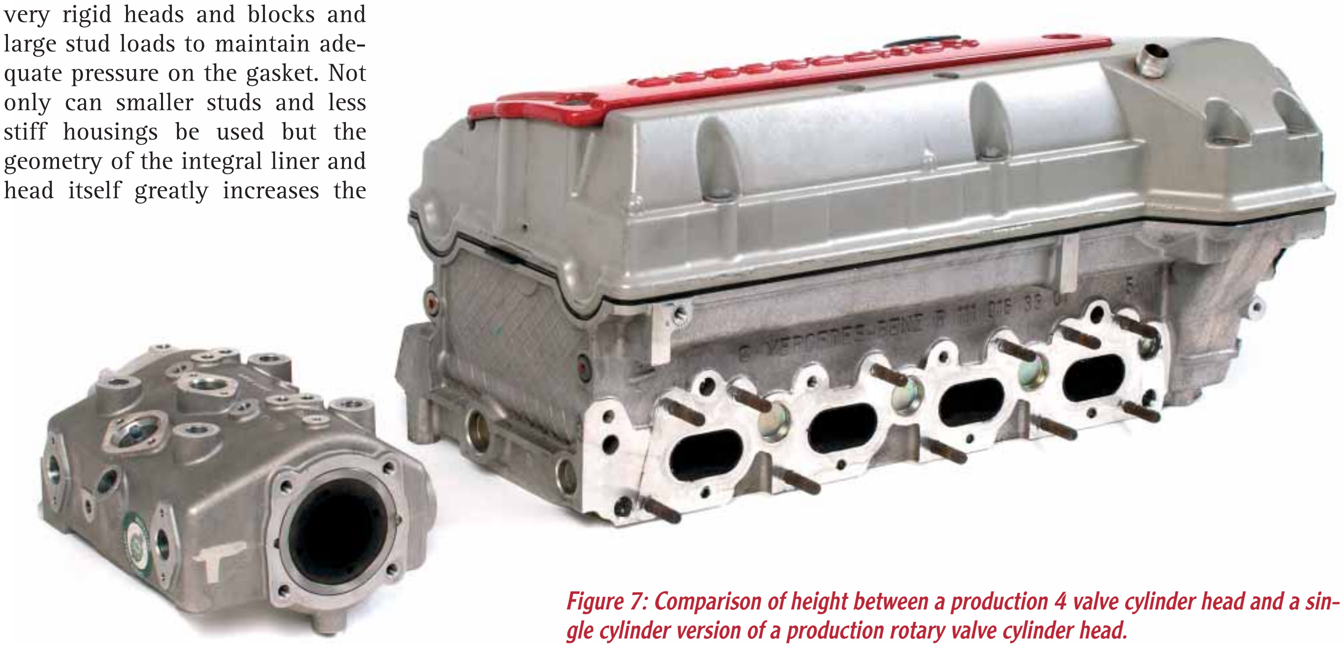

Figure 7: Comparison of height between a production 4 valve cylinder head and a single cylinder version of a production rotary valve cylinder head.