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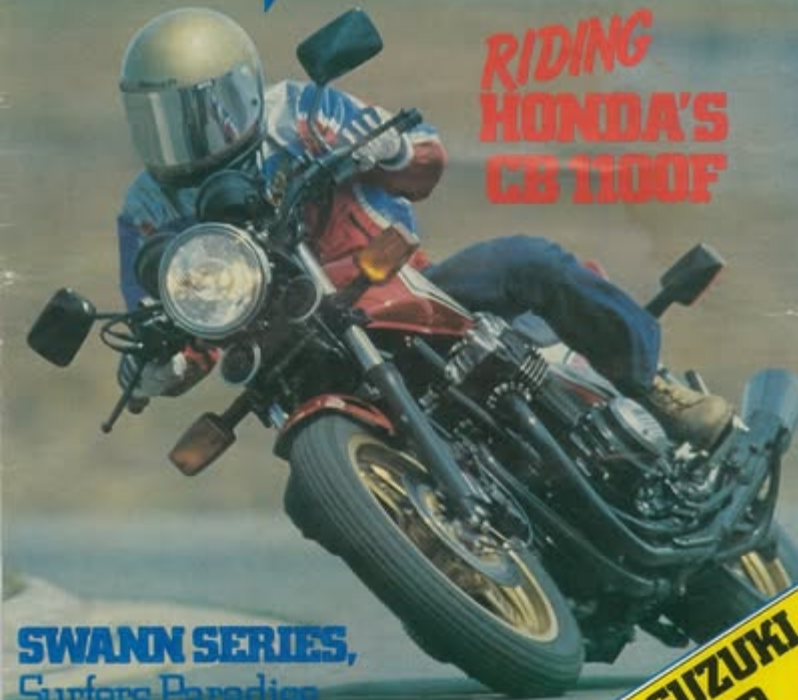
NEW ROTARY VALVE FOUR-STROKE: The Inside Story



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FOUR-STROKE BREAK THROUGH

Inside the Vial-Gabelish Rotary Valve Head

Is the poppet's merry dance nearing an end?

Rotary valves for four-stroke internal combustion engines are not new but until recently, all attempts at perfecting them met only limited success. But now two Sydney men, Peter Gabelish and Aub Vial, have taken out patents on some new designs, and feel they are on the threshold of a major breakthrough in internal combustion engines. For the past 15 years, they have worked on solving the complex and inter-related problems of gas sealing, lubrication, lubricant control and thermal distortion that have long been the downfall of rotary valve designs. Have they produced a viable design? FRASER STRONACH investigates . . .

THE limitations of the poppet valve have been recognised right through the relatively short history of the Otto cycle engine, yet despite its limitations, it has yet to be successfully challenged as a four-stroke valving mechanism.

The reasons for its success are as simple as the mechanism itself. The valve is stationary against its seat during the critical period when gas tightness is required and as well possesses an important self-sealing characteristic. When it opens and closes, it does so with little load on the sliding surface of the valve and consequently will operate successfully with minimal lubrication.

Against these inherent and substantial advantages, the poppet valve is most often criticised for the constraints it puts upon combustion chamber design, its obstruction to gas flow and the limit the presence the incandescent exhaust valve places on the use of high compression ratios. In addition, the poppet valve relies on a high speed reciprocating motion that places considerable inertial stress on the components involved. While 'valve float' may no longer be the design constraint it once was, the high number of precise components needed to produce this reciprocating motion add complexity, cost and size to an engine. In higher performance engines, where greater degrees of valve overlap are used, the emission of unburnt hydro-carbons, especially in this age of 'clean air' regulations and fuel savings, can also be a problem.

Initial attempts to produce an alternative to the poppet valve were spurred on by the limitation its reciprocating motion placed on engine rpm, although later rotary valve designers began to see the benefits an uncompromisingly shaped and cool combustion chamber offered to performance and economy.

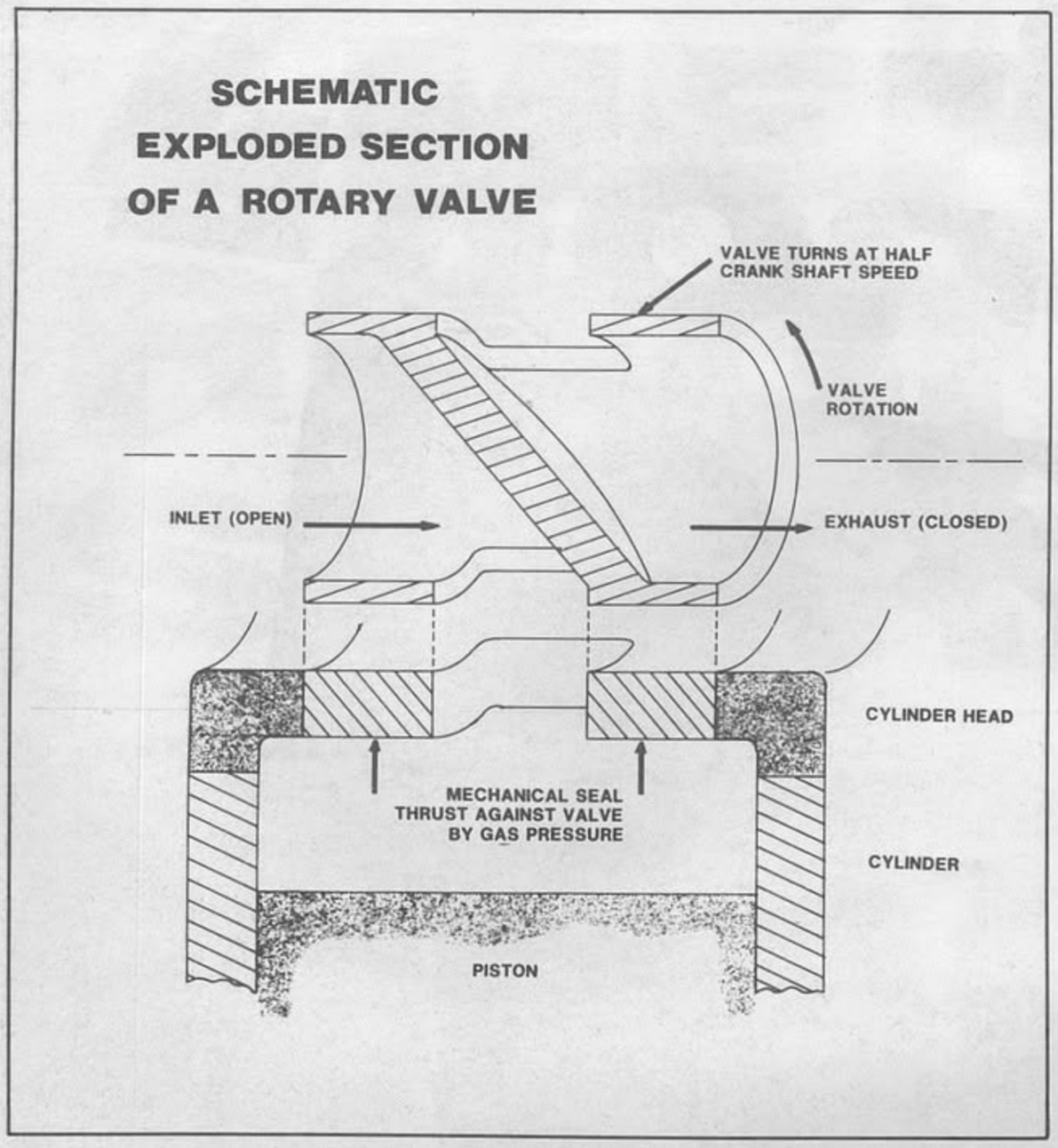
The principle of using a valve mechanism that relied on a rotating rather than a reciprocating motion was established by the Crossley engines produced between 1886 and 1902. In 1908, a four cylinder engine using a rotary valve was produced by a Mr. E. W. Lewis in Coventry, England, while a few years later a Mr. Dugald Clerk, who had earlier produced a small engine containing slide valves, described a rotary valve engine produced by the National Gas and Oil Company as having 'performed beautifully', in an address to the IAE (Institute of Automotive Engineers).

In a similar address in 1911, a past president of the Society of Automotive Engineers (SAE) predicted the gradual replacement of the poppet by the rotary valve after citing the fine performance of several rotary valved automobiles in the USA. Yet despite constantly favorable reviews and the production in 1911 by both Darracq of France and Itala of Italy of rotary valved four cylinder vehicles, the poppet valve continued to gain ascendency as the most popular valving mechanism for the internal combustion engine.

The only notably successful alternative to the poppet valve came in the form of the sleeve valve, originally invented by Mr. C. Y. Knight (patented around 1908) but reaching the high point of its development in the Burt and McCollum single sleeve valve as employed in the highly successful Bristol Hercules/Centaurus and Napier Sabre/Dagger aero engines of the Second World War.

In the period before the war, one of the better known exponents of rotary valve design, the late Frank Aspin, developed a conical valve which, according to his claims, allowed the use of high compression ratios with low octane fuel in motors of good output and low fuel use.

His design used a conical valve rotating around the cylinder bore axis in a



Schematic diagram of rotary valve shows the juxtaposition of the ports within the valve and the mechanical seal between the valve and the combustion chamber.

complimentary shaped seating, the base surface of the valve opening permanently to the cylinder and forming the major portion of the combustion space. The valve used a single port in its conical face that upon rotation of the valve aligned with one exhaust and one inlet port in the valve's seating and by doing so controlled the flow of gas in and out of the combustion chamber.

The shortcomings of this design centred around providing sufficient lubrication during the high load period of the cycle while preventing excessive oil flow during the low load phase. Aspin found with his earlier designs he could build an engine of modest oil consumption, or one with good reliability, but not both. In addition, timing the valves for optimum port opening proved difficult.

In a design patented in more recent times (1967), Aspin claimed to solve these problems by using a variable speed drive to the valve, slowing it down during the period of maximum loading (high pressure phases of the cycle) and speeding it up during the low load periods. The limitations of this system would seem to centre around the fact that each cylinder requires a separate valve and a complex drive to that valve and thus cost and complexity would seem prohibitive.

By far the most prolific and creditable rotary valve designer and builder however was the late Roland Cross, F.I.Mech.E. Cross started his work on rotary valves in the early 1920s, his son Michael later writing that the motivation behind his father's work was his amazement that a 'poppet valve engine of reasonable performance would operate at all without pre-ignition on account of the large area of incandescent exhaust valve present in the combustion chamber. He never changed his view that the development of high octane fuel provided a poor substitute for a properly engineered cool combustion chamber.'

Cross' design used a cylindrical valve, axially ported (inlet at one end, exhaust at the other) and for ease of drive, inline with the crankshaft. Rotating at half engine speed, the valve alternatively opens the inlet port and then the exhaust port to a single transfer port leading to the combustion chamber. His earlier designs used a solid valve housing using a sleeve insert employing a flexible phosper bronze lip to seal the critical interface between the valve and the combustion chamber.

While this design proved successful in limiting gas leakage and controlling the valve lubricant, excessive wear on the flexible lip proved its downfall.

Cross then came up with an ingenious idea to use gas pressure in the cylinder to control the loading on the valve via an external lever system. This system used a bridge arrangement that straddled the cylinder and the valve housing and secured to the crankcase by four studs. The valve housing was horizontally split with a roller acting as a hinge for the upper part of the housing while a resilient sealing strip on the other side made the housing slightly compressible. A raised pad on top of the split housing bore against the under side of the restraining bridge.

The cylinder, instead of being bolted down, was spigotted into the crankcase and allowed to move ever so slightly up and down, a static seal being used to retain the crankcase oil. During the high pressure phases of the cycle, the cylinder moves immeasurably upwards, the bridge restrains it and in doing so acts down upon the compressible valve housing and so ensures a gas tight seal between the rotor and combustion chamber. During the rest of the cycle, coil springs at the base of the cylinder maintain contact between the rotor and the lower part of the housing. It is during this part of the cycle, when the clamping force is reduced, that lubricant is injected onto the rotor, a scraper blade being used to prevent excess oil entering the combustion space, the excess then being returned to the crankcase.

The shortcoming of this system amounted to the fact that each individual cylinder in a multi-cylinder engine needs a separate external bridge set-up, thus adding complexity and size to an engine. In addition, the 'floating cylinder' lacked the rigidity needed to resist piston side thrust. Cross' work was interrupted by the war (although he did work on rotary valved auxiliary aircraft engines — a disaster caused by the failure of a competing engine in a type test saw the Air Ministry abandon the project) and then after the war, aircraft work — both for the USA and Britain — took priority over his rotary valve development.

The Cross rotary valve has more recently been seen in an unusual 'Cruciform' engine jointly developed by Esso and the Cross Manufacturing Company. This engine has four cylinders arranged in an 'X' pattern and uses, as well as Cross' rotary valves, another unusual design known as an eccentric crank. This does away with conventional con-rods and big and little-end bearings.

The two concepts tie in well together for the eccentric crank negates any piston side thrust while the layout of the cylinders allows plenty of room for Cross' external bridge arrangement. The engine has been reported to run well at 10.5:1 compression with 64 octane unleaded fuel, although little would appear to be published about it since its development around eight years ago.

While Cross' name is without doubt the most significant one in rotary valve development to date, he is by no means the only one. In Australia during the Second World War, the Division of Aeronautics of the Council for Scientific and Industrial Research (CSIR) tested a rotary valve designed by a Mr. H. S. McLaren of Melbourne, then went on to develop a rotary valve of its own based on some of McLaren's principles.

Following the success, particularly by Cross before the war, interest in rotary valves reached a peak in the 1950s. In the US, Merritt Zimmerman designed and built a 250 cm^3 45 degree V-twin using axially ported cylindrical rotary valves, the bike achieving some success in enduro events during 1954/55. At this time, NSU was experimenting with rotary valves and so too was Norton.

Back in Australia, a Mr. D. G. Dunstan patented a rotary valve cylinder head that could be adapted for use with Holden inline six cylinder motors. Aparently, these engines achieved some success in power boat racing.

About this time, a young Peter Gabelish conceived the idea of a rotary valve, not being aware at the time of the many designers who had previously experimented with the idea. In conjunction with Aub Vial, Peter's partner to this day, work begun on the idea around 1968. Their first rotary valved engine, based on a MV Agusta 125 road-racer, first ran in 1971.

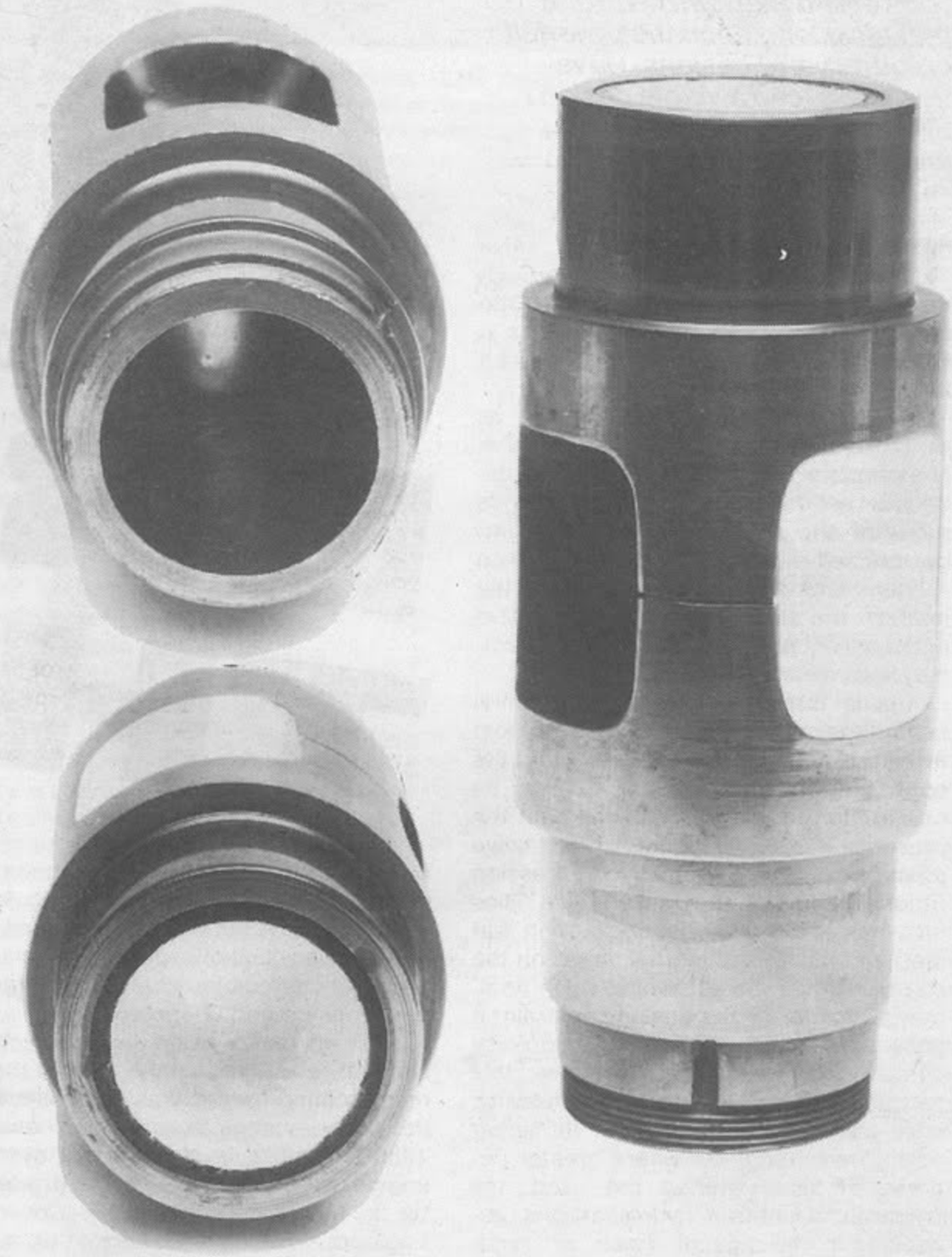
With the involvement of noted Australian automotive design engineer and author P. E. Irving as a consultant to the project, Gabelish and Vial switched their development from the MV to a Yamaha XT500 in 1976. Since the start of the development phase using the Yamaha, the project has received considerable help from Sydney motorcycle engineer Mark Walker, both in the form of his considerable engine know-how, and through the use of his dyno and machining facilities.

The development process has not been an easy one. The work has been carried out virtually as a back yard/part time affair and like many such engineering projects that start from scratch, has had many set-backs. The sort of problems Gabelish and Vial have come across have long confronted rotary valve designers; those problems being inherent to the concept of rotary valves.

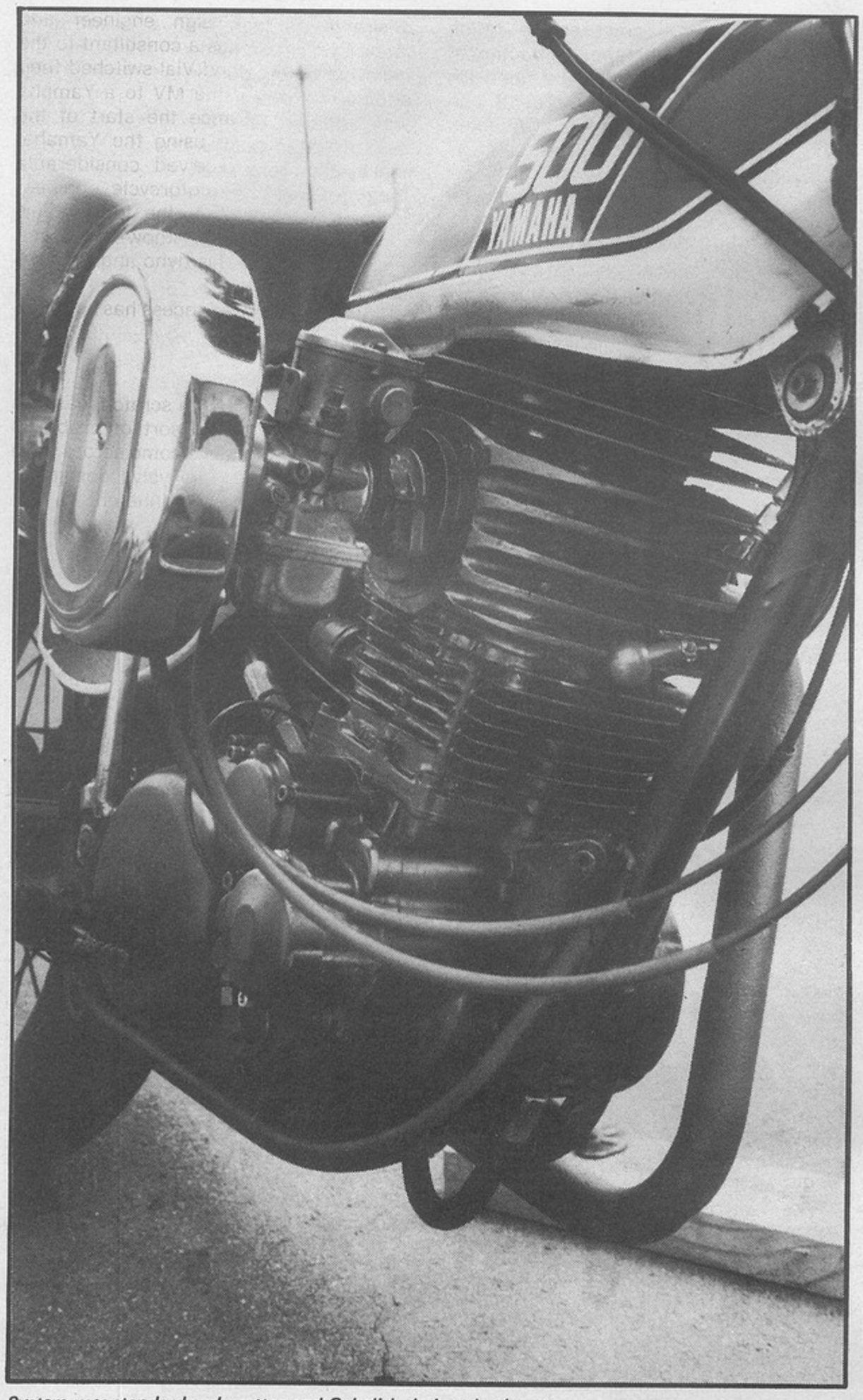
The first and most important problem to overcome is sealing the combustion chamber. Gas leakage must be prevented from occurring at the interface between the moving components. All rotary valve mechanisms must by definition have components which are moving relative to one another during the high pressure phase of the engine cycle. If any appreciable leakage does occur, it is destructive to the components along the leakage path due to the heat carried by the escaping gases.

The relatively moving surfaces must also be adequately lubricated, preferably in the hydrodynamic state. That is, the surfaces must be separated by a film of lubricant thick enough to prevent any metal-to-metal contact.

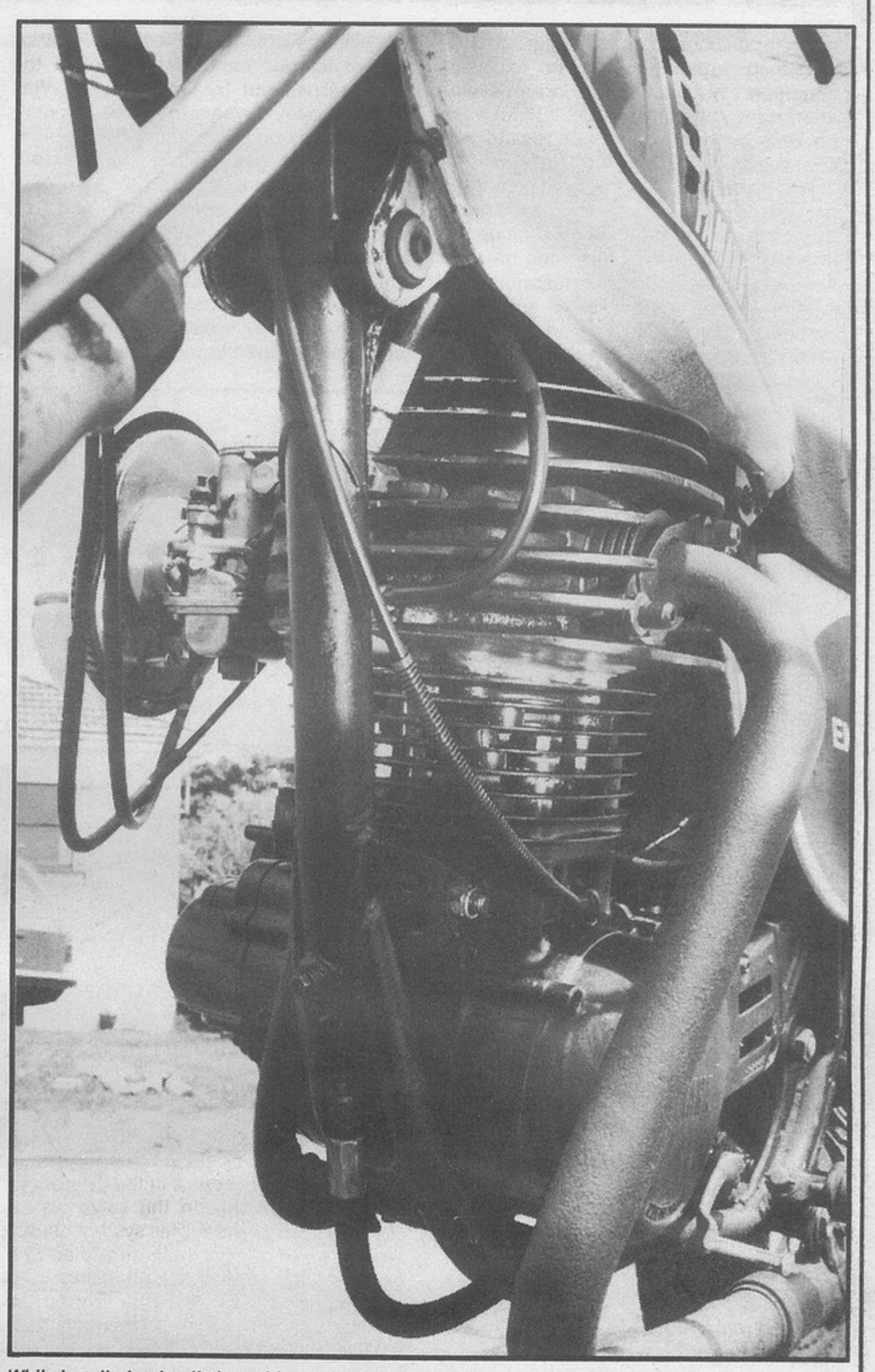
The environment in a rotary valve cylinder head tends to work against meeting these requirements in that high cyclic pressures tend to force the surfaces together, thus over-loading the lubricant. At the same time, the high temperatures involved tend to lower the viscosity and hence the load carrying capacity of the lubricant. In addition, the cyclic nature of the four-cycle engine tends to promote thermal distortion of the



Inlet port (black) is at the threaded end of the rotary valve. Exhaust port (white) exits from the opposite end. Upon rotation of the valve, both the ports in the middle alternately line up with the transfer port to the combustion chamber.



System uses standard carburettor and Gabelish designed exhaust.



While installation is a little untidy on the Yamaha bottom-end, a production rotary valve engine would employ a valve train designed to give more conventional placement of exhaust and carburettor.

components due to the uneven heating.

If thermal distortion is allowed to occur, it is destructive because any high spots generate local heating, the effects then being cumulative.

Finally, lubricant must be prevented from entering the working gases at any point in the engine and under any operating conditions. Over-run and idle both create sub-atmospheric conditions in the combustion chamber and the ports tend to draw lubricant into them. To be successful, a rotary valve must meet all the above criteria with a safety margin great enough to be reliable, even under the most adverse operating conditions.

After 15 years development, including numerous hours of dyno testing and some 40,000 kilometres of on-road testing, Peter Gabelish and Aub Vial are confident that with their rotary valve mechanism they have resolved these problems, and in doing so have produced a viable rotary valve design.

That basic design, in as much as it uses an axially ported, cylindrical valve rotating at half engine speed, is not dissimilar to that of Roland Cross. Unlike the Cross design however, the cylinder and cylinder head are rigidly mounted to the crankcase while the valve components are all internal to the cylinder head. Sealing is accomplished by a floating seal (see diagram) which achieves a self-sealing interface to the valve under the thrust of the gas pressure in the cylinder. This sealing method has been the basis of previous rotary valve attempts and it is the perfecting of this mechanism that has taken up most of Gabelish and Vial's 15 years effort.

Due to patent rights taken out on the critical areas of the design, full details of the floating seal and the lubrication and oil control systems integrated into the floating seal cannot be covered here, although a confidential disclosure has been made to the author. It can be said from that disclosure that the floating seal is very simple and within the realms of conventional automotive engineering while the integral oil control system requires no special components, such as metering orifices, check valves or scrapers. In addition, the system requires no adjustments and is readily adaptable to in-line multi-cylinder designs.

In an attempt to validate the claims made by Gabelish and Vial, the author has ridden their rotary valve equipped XT500 on several occasions, the most notable of which was a 1000 kilometre two day run. This run was designed to test the reliability and general on-road viability of their design as well as providing comparison to an acompanying standard XT500 to check the rotary valve engine's relative power characteristics and fuel consumption.

In addition to the two XTs, a Honda CX500EC was also present on the run. For fuel consumption comparisons, usual road test procedures were used. These procedures include topping the bikes up at the same petrol bowser, while on the road the bikes were kept close together without getting in each other's slipstreams, with the riders swapping over to negate any rider orientated differences. Open road speeds were kept up around 120 km/h with the bikes generally pushed along quite hard. No special economy riding techniques were employed.

Distance readings were taken from the odometers, that of one of the bikes disregarded as it was constantly five percent short of the other two. The two odometer readings considered true were always within one percent of each other and were then averaged. One of these two odometers was later checked against road side markings used on expressways for checking speedometers and within the limitations of this test it proved to be accurate.

The results of the fuel consumption checks averaged out over the 1000 km were as follows. The rotary valve equipped bike averaged 3.64 l/100 km (77.3 mpg), the standard XT500, 5.38 l/100 km (52.3 mpg) and the Honda CX500EC, 4.98 l/100 km (56.5 mpg). This represents an average fuel saving by the rotary valved XT500 over the standard poppet valve XT of an astonishing 32 percent. It should be noted that both the rotary valve and the poppet valve XTs were using the standard carburettors, identical exhausts and equivalent overall gearing. Tyre pressures were standardised and likewise important aerodynamic considerations such as ride positions (handlebar width and height) were similar on the two bikes.

In a later run, the rotary valved XT was compared against a 1982 XT550, which is claimed by its manufacturer to offer — though the use of four rather than two valves and a special dual throat, composite carburettor — more economical running than an XT500. The standard XT500 was also present on this run during which speeds were kept around 130 km/h. On this occasion the rotary valved bike showed a fuel saving of 38.2 percent over the XT500 and 34.8 percent over the XT550. The rotary valved XT has also been compared against a BMW R80 G/S, recording a fuel saving over this bike of 41.4 percent.

It must be emphasised that during these consumption checks all the bikes were ridden quite hard, and while 3.6 l/100 km consumption is not out of the ordinary for easy 90 to 100 km/h running, it is quite exceptional for 120 to 130 km/h speeds.

In addition to this fuel saving, the rotary valved XT500 showed up more than favorably against the standard XT in its power characteristics. Top-end performance of the two was not noticeably different but at low rpm and more especially in the mid-range, the rotary valved motor was noticeably stronger. In addition, the motor displayed none of the harshness usually found with high compression motors (11.5:1 in the subject motor). This 'soft' feel to the power delivery combined with the motor's increased flexibility and decreased engine noise (no valve clatter) made the rotary valved bike considerably more pleasant to ride than the standard poppet valved XT.

Despite its high compression there was also no sign of 'knocking', even under full load, low rpm conditions and in fact the subject motor will even run on standard grade fuel without any problems. Oil consumption checks revealed negligible oil consumption over the 1000 km while on-road observation from behind the rotary valved bike revealed no visible smoke from the exhaust, even when the throttle was opened up after a long period of over-run. Likewise, compression checks both before and after the run indicated no problems with maintenance of the gas seal.

Reliability wise, the motor ran without fault, showing no objection to long hard, full-throttle up-hill runs — even when temperatures were in excess of 28 degrees centigrade. After the run, the rotary valve mechanism was stripped

down for inspection, the working surfaces of which proved to be in excellent condition. Subsequent, shorter evaluation rides (usually around 200 km) gave no reason to question the results obtained from this initial 1000 km run.

The Gabelish/Vial rotary valved engine has also spent some time on an engine dyno, the results obtained backing up the impression of the engine's good on-road flexibility and excellent fuel economy. At present, these dyno results are being certified by an automotive engineer, the certification process involving dead weight testing of the dyno, validation of the testing procedures and ratification of the results.

Peak power obtained from the subject motor is around 21.1 kW at 5700 rpm while Yamaha claim a standard XT is good for around 23.4 kW at 6500 rpm. Of more significance however are the torque figures. Factory claims put the standard XT at 38.2 Nm at 5500 rpm (*Cycle World* magazine recorded 37.9 Nm at 5500 on its dyno) while the Gabelish/Vial motor has recorded 41.4 Nm at a lowly 3500 rpm.

Equally impressive are the 'specific' fuel consumption figures recorded on the dyno. Specific fuel consumption is an engineer's way of measuring fuel use, relating the amount of fuel used to produce a given unit of power for a given period. Traditionally in this country, specific fuel consumption has been measured in pounds of fuel used per horsepower-hour (lbs/hp.h) but more recently with metrication this unit has given way to grams of fuel used per kilowatt-hour (g/kW.h). In general, specific fuel consumption is at its greatest when an engine is subjected to low loads, since this is where the ratio between idling loses (due to friction, leaks etc.) and the brake horsepower is most unfavorable.

The best specific consumption recorded by the Gabelish/Vial engine has been a low 220 g/kW.h (0.36 lb/hp.hr). In comparison, most modern four-stroke motorcycle engines record anywhere between 270 and 340 g/kW.h while four-stroke car engines tend to be more in the 300 to 380 g/kW.h region. In fact, the Gabelish/Vial figure is more in-line with that achieved by contemporary diesel motors.

All of this would be of less significance except for one important aspect of the work carried out by Gabelish and Vial. Over the past 15 years they have concentrated solely on overcoming the inherent problems of gas sealing, valve lubrication, heat transfer and lubricant control. They have spent little time on experimentation with combustion chamber shaping, valve timing, port shapes or other aspects of the design which would optimise the power and/or economy of their motor. Yet despite this, and the fact the standard XT500 has all the benefits of 80 years of accumulated poppet valve technology, the Gabelish/Vial motor still shows up more than favorably when compared on these terms.

Looking at the Gabelish/Vial valve more generally, it is clear it offers a number of significant advantages over poppet valve systems. Firstly, it offers a considerable gain in thermal efficiency (Gabelish claims 20 percent) over that of contemporary poppet valve engines. This comes about in two main ways. Under the Laws of Thermodynamics, a higher compression ratio means higher thermal efficiency. The upper limit for the compression ratio for any engine is governed by the octane rating of the fuel used and if the maximum compression ratio is exceeded, combustion 'knock' occurs. The Gabelish/Vial rotary valve head allows compression ratios at least 2.5 ratios higher than that possible with the conventional poppet valve head.

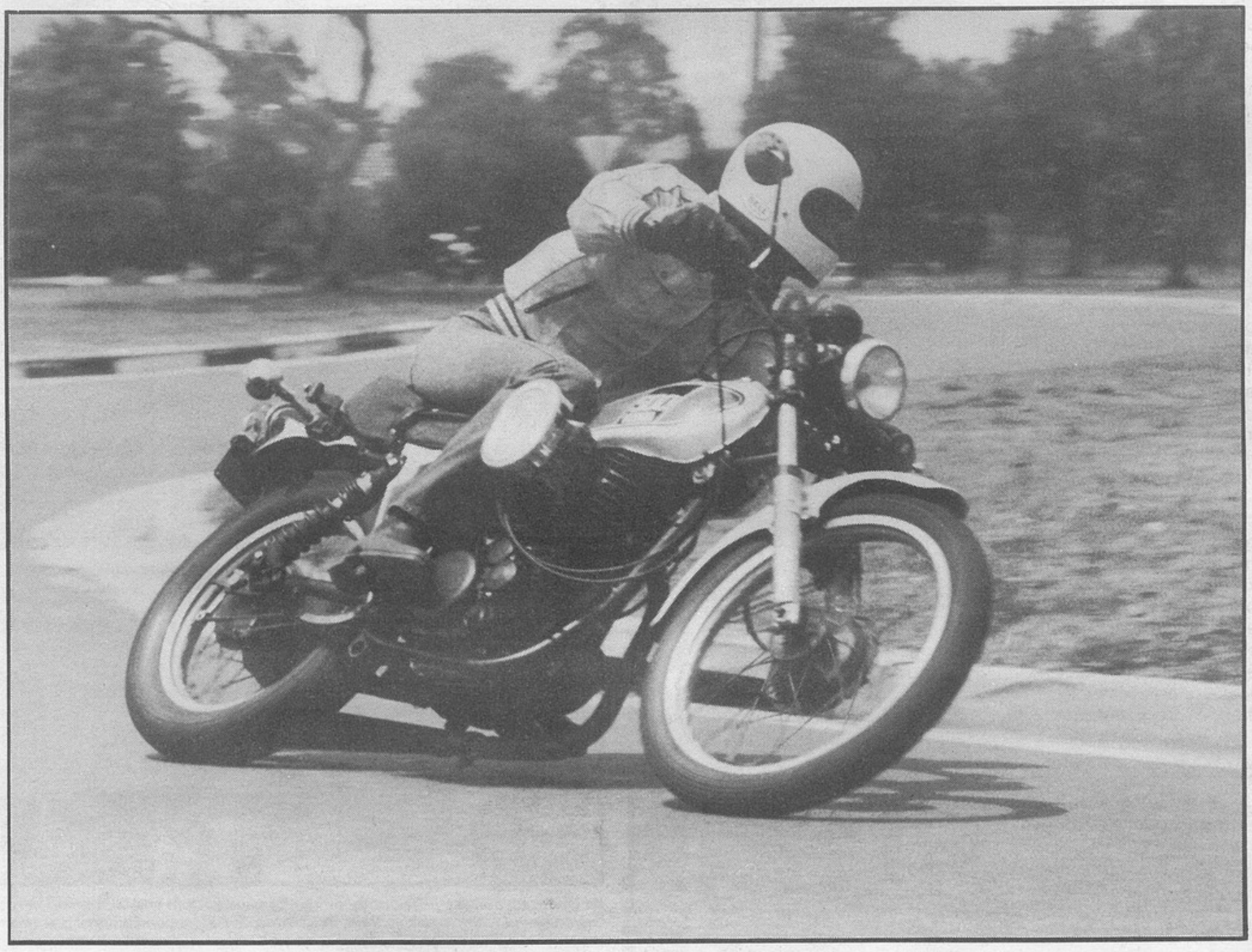
The second feature contributing to the greater thermal efficiency is the reduced heat (energy) loss to the cylinder head. A rotary valve system allows much greater design flexibility in the control of surface temperatures within the combustion chamber, as well as placing little compromise on the shape of the combustion space. A shorter flame path allows the use of less ignition advance, or lead time (the Gabelish/Vial motor uses only 65 percent of the lead time of the standard XT) and consequently more effective work is done on the piston by the energy released in the combustion process.

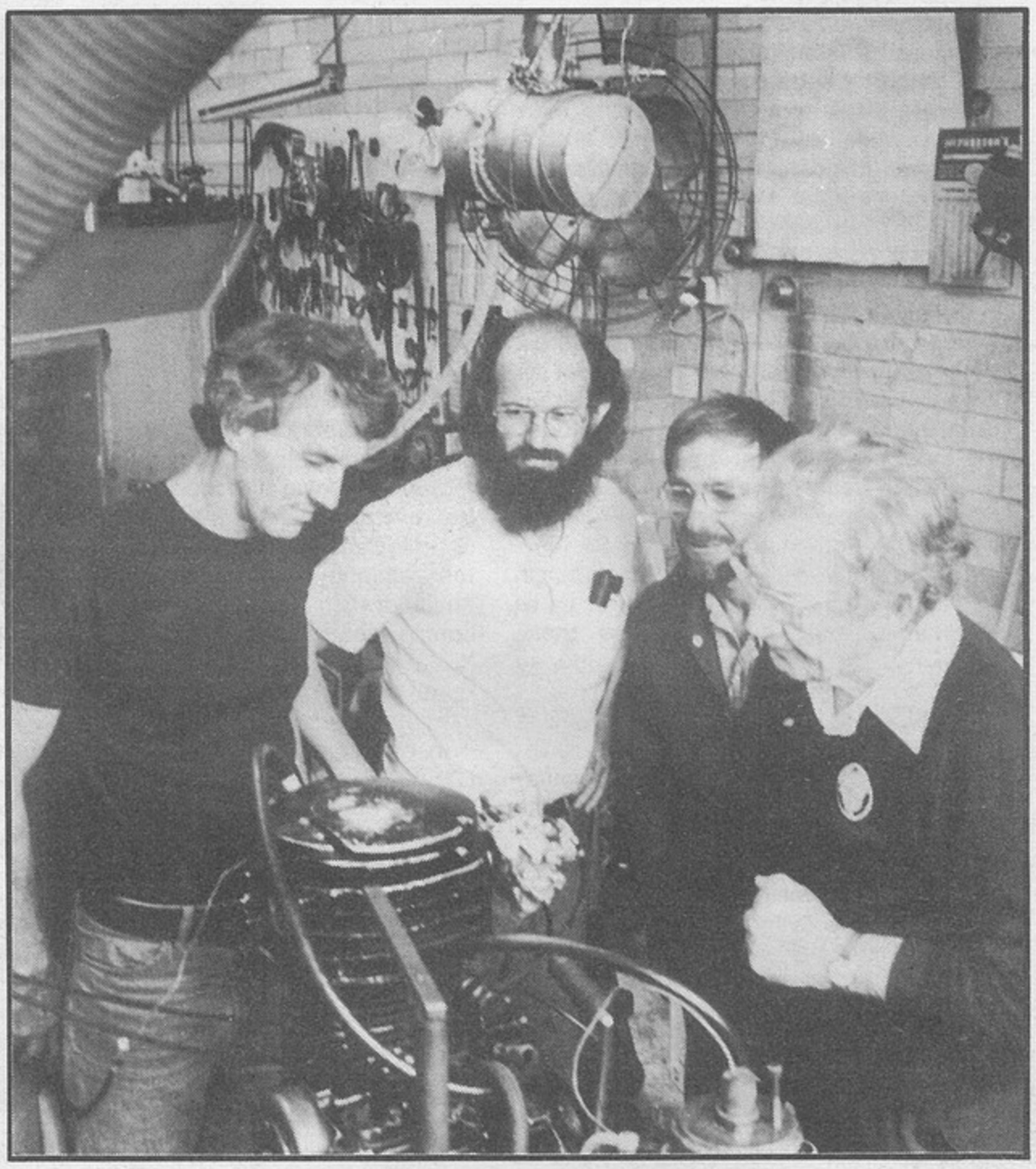
Of increasing significance in today's world is the rotary valve's lead-free capability. Due to the reduced tendency to produce combustion knock, engines employing rotary valves could operate with contemporary compression ratios with fuel of 60 to 70 octane. Production of low octane fuel eliminates the need for lead based octane 'enhancers'. It can also decrease the cost of fuel production as octane boosting techniques such as 'cracking' are energy expensive.

In contemporary engines, the lead used in fuel also tends to cushion the sealing faces of poppet valves while the use of lead-free fuel can lead to excessive poppet valve seat wear. This cushioning is not required for rotary valves. The use of lead free petrol would be environmentally desirable as high lead concentrations found in children living in urban areas is believed to be due to the use of lead additives in petrol.

In addition to these benefits already demonstrated possible by the Gabelish/Vial system, rotary valves in general have the potential to reduce the levels of three other exhaust emissions known to create environmental health hazards.

The rotary valve's compact combustion chamber with its low surface to volume ratio and proven ability to run with less valve overlap than is common with





TOP: Peter Gabelish aboard his rotary valve equipped XT500. The bike has covered 40,000 kilometres of on-road development. ABOVE: From left; Phil Irving, Aub Vial, Mark Walker and Peter Gabelish prepare to dyno test the rotary valved engine.

poppet valve engines (the Gabelish/Vial set-up uses around 40 percent less overlap than the standard XT) should be of benefit in reducing the amount of unburned hydro-carbons released to the atmosphere.

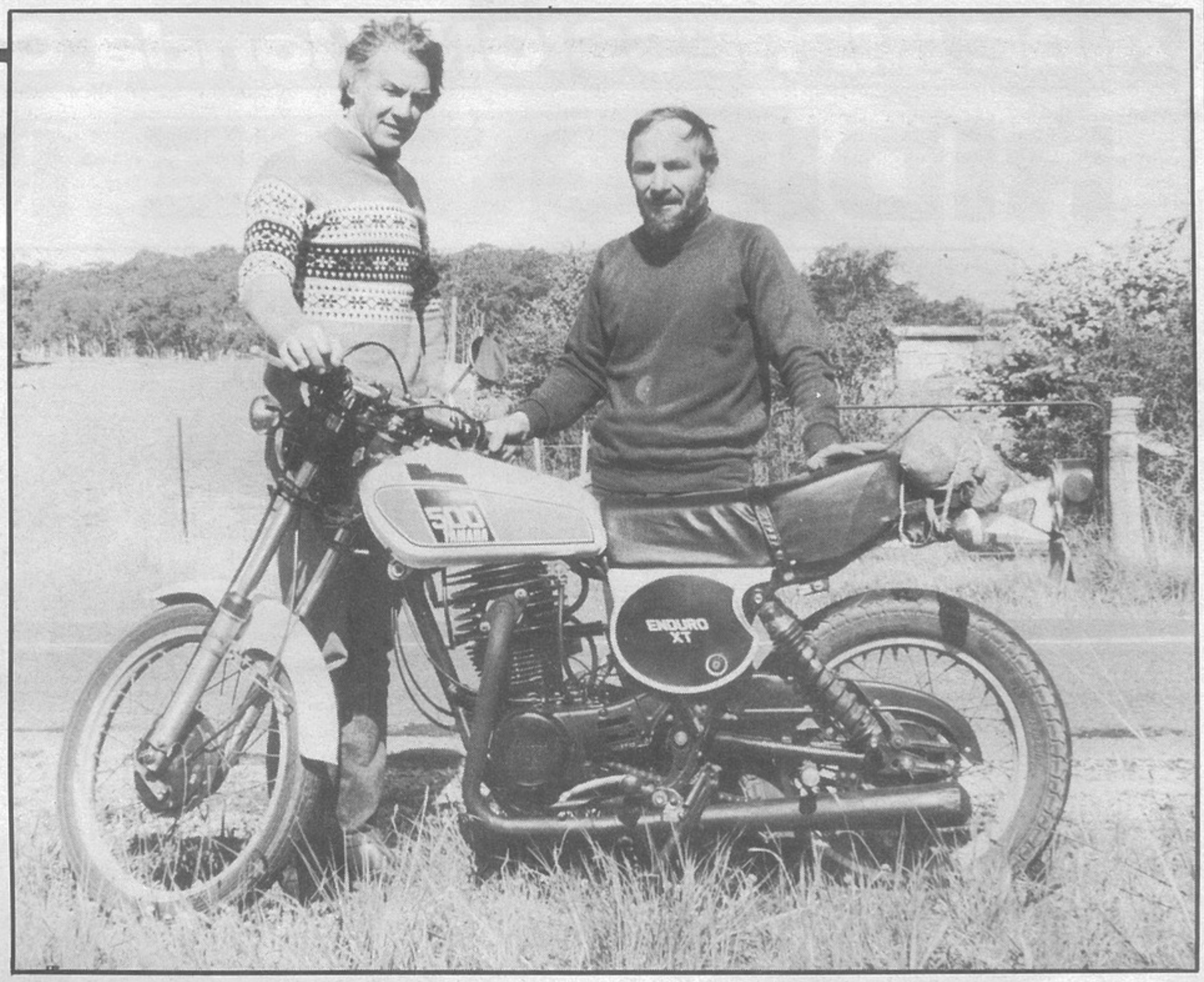
The Gabelish/Vial rotary valve has also exhibited the ability to run evenly on very low air/fuel ratios and thus carbon monoxide emissions can be reduced. In fact, the subject engine can be made to run with the exhaust pipe a dull red at fast idle without misfire, by adjusting for lean mixtures.

The short ignition lead times mentioned previously and the uniform combustion chamber temperatures should reduce the tendency for high temperature 'end' gases and hence nitric oxides to form in the combustion chamber. Nitric oxide is known to be one of the atmospheric pollutants involved in the formation of 'acid rain'.

Maintenance, or rather the lack of it, is also one of the attactions of a rotary valve. Because the sealing surfaces operate in a fully lubricated state, there should be no deterioration of the sealing function during normal life of the engine. On the other hand, poppet valves tend to wear out their seating surfaces, generally increasing their output of pollutants as the engine wears.

It has often been said that it matters little how clever an invention is, but rather it is more important how timely it is. After all, many of today's 'state-of-the-art' features found on contemporary motorcycles were seen in one form or another in the early days of automotive history, but it is only now that the market is receptive enough to make them popular.

Likewise, rotary valves have been around for many years, albeit most of them with design problems, but in the current climate of dwindling oil supplies and increasing concern over atmospheric pollution they have become more desirable than ever.

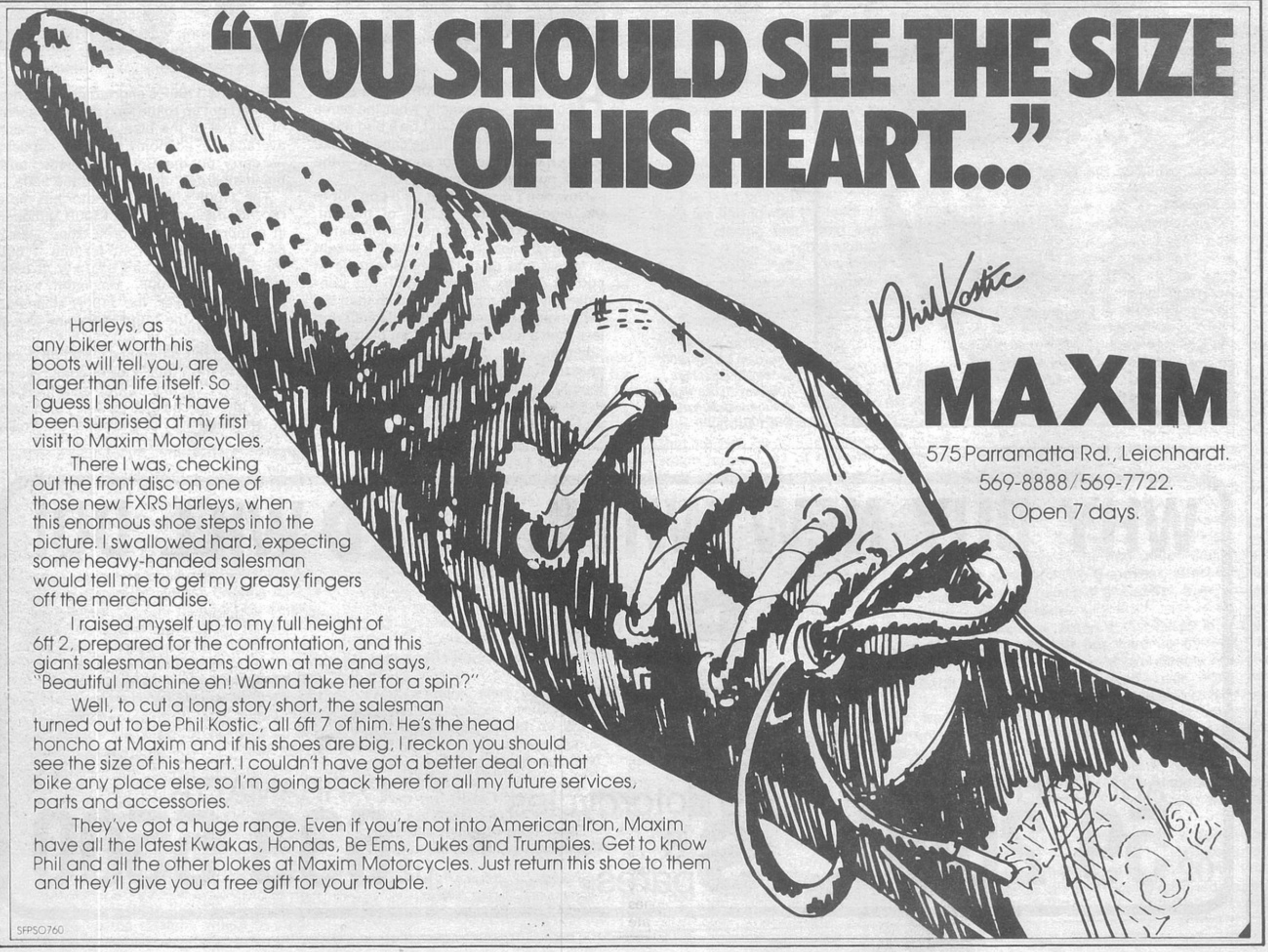


Peter Gabelish and Aub Vial are confident that the break throughs they have made, have, at last, solved the critical design problems of the rotary valve, and from the author's experience with their engine, especially in regard to the many trouble free kilometres covered on their rotary valve equipped bike, this would appear to be the case.

After certification of their dyno results, especially those regarding specific fuel consumption, all that is needed is for an enterprising automotive or motorcycle manufacturer to take up their patents and we may see, at last, a real alternative to the poppet valve. □

Peter Gabelish and Aub Vial with their rotary valve equipped XT500 after it had just completed another successful 1000 km run.

"YOU SHOULD SEE THE SIZE OF HIS HEART..."



Harleys, as any biker worth his boots will tell you, are larger than life itself. So I guess I shouldn't have been surprised at my first visit to Maxim Motorcycles.

There I was, checking out the front disc on one of those new FXRS Harleys, when this enormous shoe steps into the picture. I swallowed hard, expecting some heavy-handed salesman would tell me to get my greasy fingers off the merchandise.

I raised myself up to my full height of 6ft 2, prepared for the confrontation, and this giant salesman beams down at me and says, "Beautiful machine eh! Wanna take her for a spin?"

Well, to cut a long story short, the salesman turned out to be Phil Kostic, all 6ft 7 of him. He's the head honcho at Maxim and if his shoes are big, I reckon you should see the size of his heart. I couldn't have got a better deal on that bike any place else, so I'm going back there for all my future services, parts and accessories.

They've got a huge range. Even if you're not into American Iron, Maxim have all the latest Kwakas, Hondas, Be Ems, Dukes and Trumpies. Get to know Phil and all the other blokes at Maxim Motorcycles. Just return this shoe to them and they'll give you a free gift for your trouble.

Phil Kostic

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