THE HONDA CR-72

THE PAST AS FUTURE

By Kevin Cameron

● In the last two seasons it has become obvious that the current four-stroke machines in American motorcycle roadracing have no chance against the two-strokes. Some people feel that an unfairness is being perpetrated, and this inequity should be corrected by new rules. But there's another viewpoint. The present one-sided affair in racing is not so much a result of inherent advantages of the two-stroke principle over the four-stroke one as it is of the financial or technological unwillingness of the four-stroke makers to build equipment on a par with the two-strokes.

A close examination of a high quality four-stroke design confirms this view. The CR-72 Honda is one showcase for the innovations created in Honda's rapid rise to international racing glory in the 1960s. The machine is a Honda production racer. It is a 54 x 54 mm, dohc 250 cc twin, giving a claimed power of 40 bhp at 12,000 rpm.

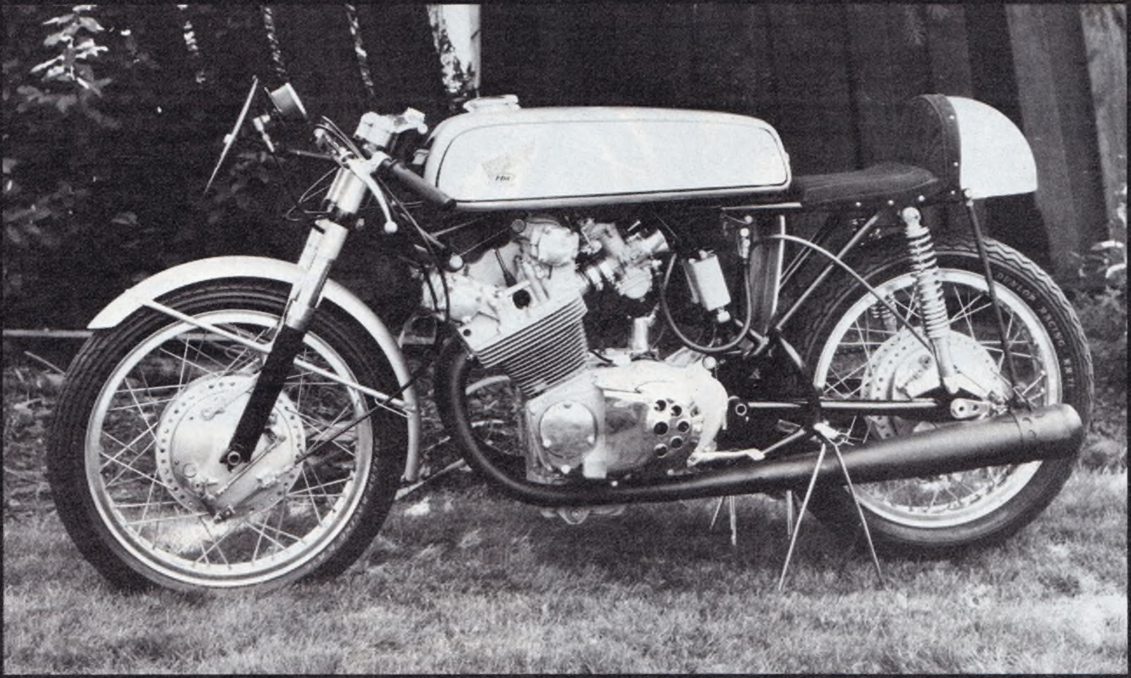
It took Honda three years of trying before they won their first world championship (the 250 in 1961) in international roadracing. But after that, with a dizzying display of mechanical virtuosity, they won again and again with twins, fours, fives, and even a six cylinder machine.

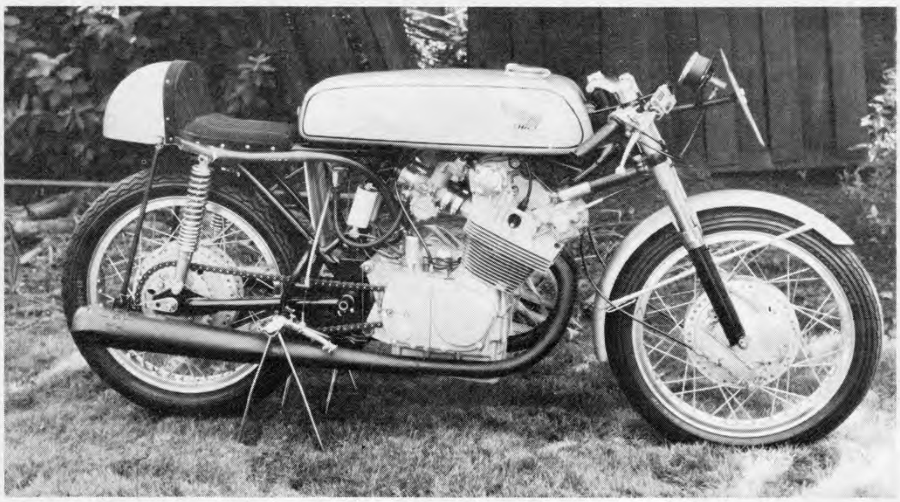
Traditional fans were horrified to see their Italian icons smashed by newcomers, and chauvinistic things were said to the effect that the Honda machines represented nothing new, that they were just refined copies of Gileras, MVs, or Guzzis.

At the same time, a new group of racing aficionados was growing up, who watched the Japanese successes with almost religious awe, who collected every scrap of information about the Honda machines, and who learned the novel magic phrases, *Four valves per cylinder, Eight speed gearbox, Seventeen-thousand rpm.*

A new tradition was created: millions of people learned the Honda name, bought the street machines, and came to believe in the invincibility of Honda's four-stroke engine technology.

I was among those millions. I pored over catalogs and magazines, compiling





notebooks full of statistics, measurements made from pictures, impressions by Honda team riders, anything at all that would help get me closer to knowing *how they did it.*

I even tried to race Honda street machines fashioned into racers, but learned, as so many did, that when Honda means a machine to be a street bike, they are usually right. Racing interested me more than brand loyalty, so I turned away from the Hondas to the new and available Yamaha production racers.

In the early sixties, when Honda success was still new, the company made a number of high rpm, dohc 50 and 125 cc production racers. These made a niche for themselves in club racing, but were well below standard for international racing.

Much smaller numbers of 250 and 305 twin-cylinder production racers were built, supposedly to provide rides for Honda teamsters in non-international events. These were sold to the riders at season's end, and they then filtered into the hands of the public. They weren't a great success. Handling was poor though power was considerable. Parts production for these models ceased in 1965, so it became necessary to "know the right people" to get spares. Gradually the machines dropped out of circulation.

Apart from this, the big CR's can be looked at in another way. Twelve-thousand rpm from a 54 x 54 mm engine translates to 4250 fpm piston speed, a very high figure by any standard.

Forty horsepower from a 250 is ho-hum in this age of 50 bhp Yamaha twins, but consider this: double up this twin into a 500 four and you have 80 bhp, a figure that is almost competitive today. Treble it into a 750, and you have the staggering sum of 120 bhp, a number that our present day "Formula 750" machines have yet been able to reach.

Surely then four-stroke technology is far from dead if a thought-experiment with a ten-year-old design can come up with horsepower that's competitive today.

A six-cylinder 750 would be costly, even if the new rule were adopted, requiring only 25 machines for AMA approval, but one should remember that Benelli is going ahead with plans to market a six-cylinder street machine.

Let's look at the numbers. The formula relating bhp, bmep, rpm, and displacement is:

$$\text{Bhp} = \frac{\text{Bmep x Rpm x Displacement}}{\text{Constant}}$$

If we have 40 bhp at 12,000 from a 250 engine, the bmep (brake mean effective pressure) must be 175 psi. This is a good figure today, but not an outstanding one. The apparent ceiling for unsupercharged four-strokes on gasoline is about 200 psi, the bmep of the current Cosworth GP car engine. (450–460 bhp @ 10,000 rpm from 3000 cc) This car engine is water-cooled, fuel injected, and CDI-sparked, all things that the CR-72 is not.

Therefore you can see that this is still a very refined piece of hardware, not to be scoffed at in any sense. Someone may point out that Norton's famous Manx engine could come very close to a 200 psi figure in a good example. That's true, but there was a sacrifice made to get it. The Manx has very pronounced "megaphonitis," that narrowness of powerband that comes from heavy dependence on wave action in the inlet and exhaust pipes, on long cam timings, and on large overlap.

The Manx has been around for a long time. Was Honda missing something, or were they working the compromises some other way? Honda's way was a very different one, as we shall see.

Among my notes from that period ten years ago are graphs showing the advances in bmep made by each of the great racing companies, year by year. Honda's "progress report" is unique, because the figures rise, then actually fall! The rise takes place in Honda's early period, from the beginning until their first GP win, as the designers searched out the answers to basic engine problems. This we can understand, but why do the figures drop through the classic years, 1963–1966? Isn't progress supposed to be steady? This brings us to the central point, the basis of Honda's racing design philosophy.

When bmep is raised to the highest possible level, through the use of strong pipe tuning and long valve timing, the torque curve shows the resonance peaks, and becomes steep. Instead of doing this, Honda settled for a somewhat lower bmep in order to get the desirable flat torque curve that makes for a very rideable racing motorcycle. Then how did they get the horsepower back, after "throwing away" bmep? By raising rpm through cylinder multiplication.

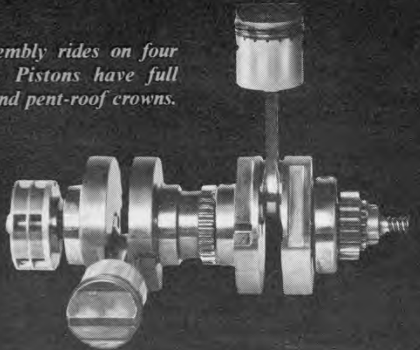
Since peak rpm is roughly limited by stroke length, then if the displacement is held constant, and the number of cylinders is increased, the stroke of each will become shorter, and rpm capability is raised. The final statement of this philosophy was the 250cc six-cylinder racer, capable of some 19,000 rpm and over 60 bhp.

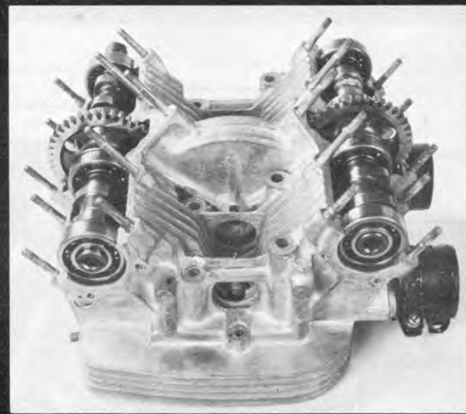
It sounds easy. It wasn't.

Anyone who has worked with racing four-strokes is all too familiar with the problems of high rpm. Piston rings break. Rods stretch and snap. Bearings fail. Valves float and bend. Honda had their work cut out for them, but these were problems of machine design, not gas flow.

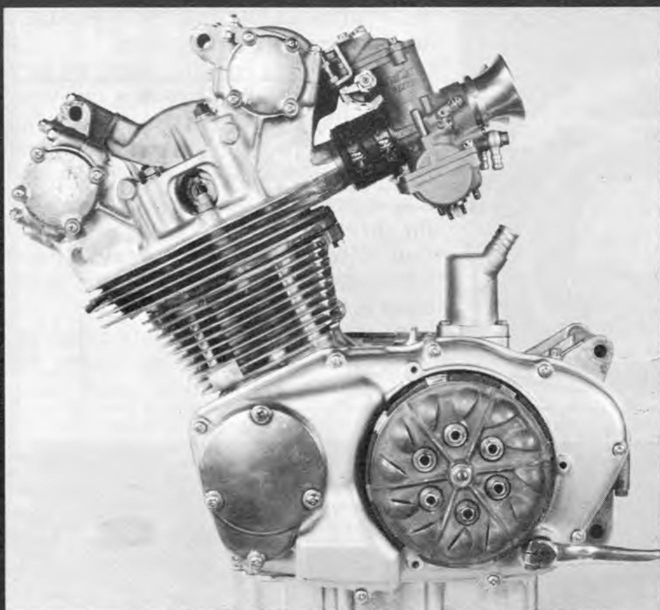
Thinner rings, better materials and designs whittled away the peripheral problems, leaving a classic vicious circle as the

Crankshaft assembly rides on four main bearings. Pistons have full skirts, 3 rings and pent-roof crowns.

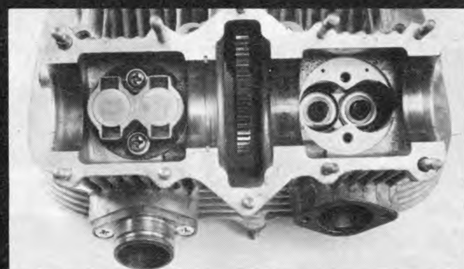




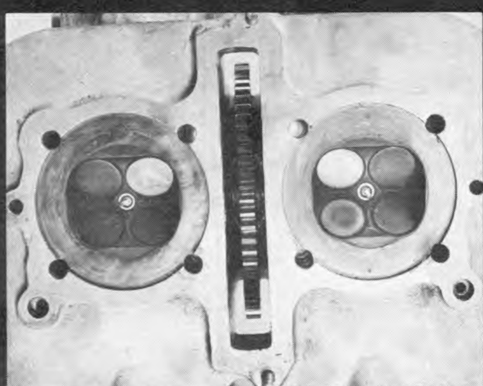
Engine had each camshaft running on four ball bearings. Spur gears drove the two overhead camshafts.



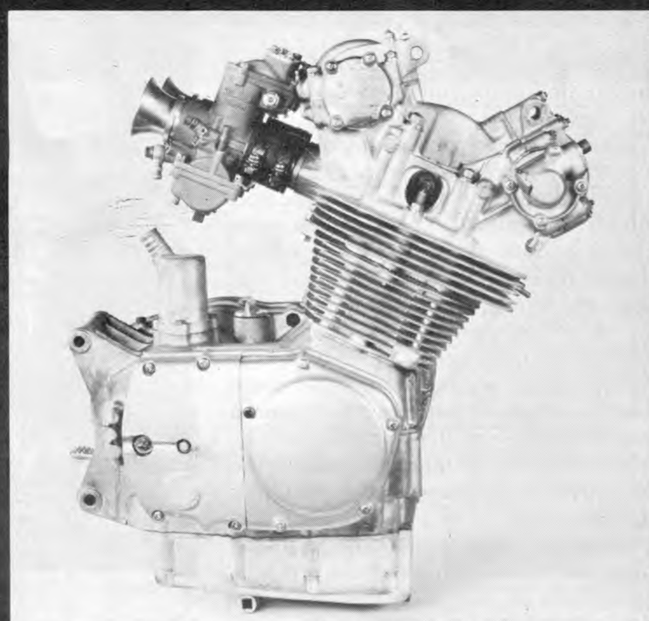
A dry clutch transmitted about 40 hp to a close-ratio six-speed gearbox.



On left two tappets are installed in the guide block. With block removed, valve spring cavity is exposed.

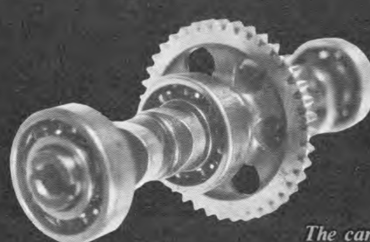


Pistons' view of four-valve heads. Intakes are 23.6mm in diameter while exhausts are 22mm across.

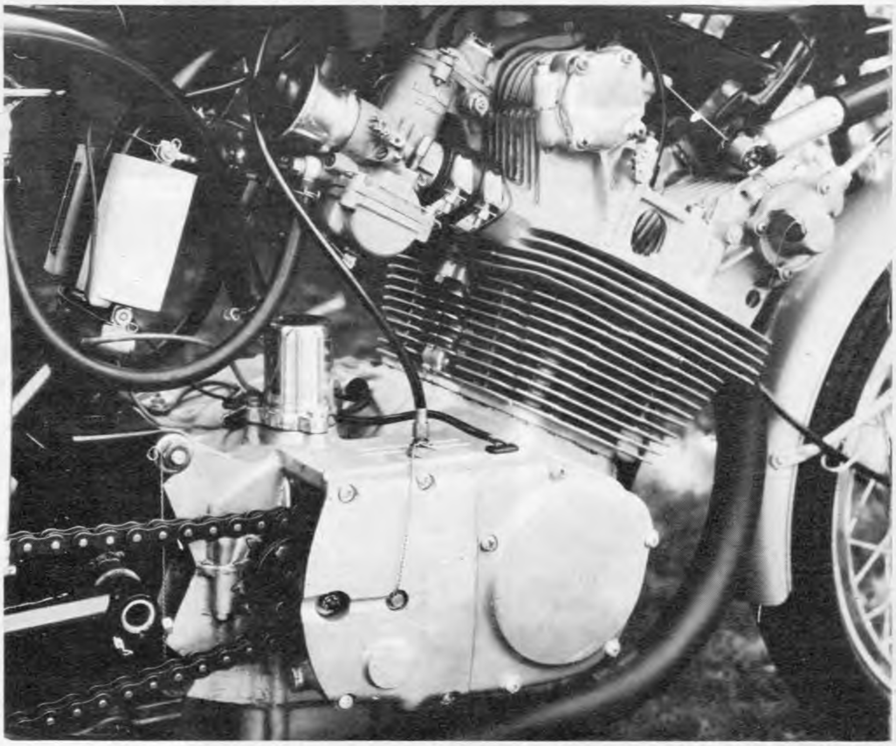


CR-72 racing engines were sand-cast and weigh a hefty 132 lbs.

Upper tier: valve, inner/outer springs, retainer, keepers and tappet. Middle: nested assembly. Lower: block minus tappets.



The camshafts have fat and fast acceleration lobes. Peak acceleration on cam is 1575 Gs.



outstanding and central problem—valve gear design.

The gas flow people want the valves to open and close as rapidly as possible, to reduce throttling and losses in the port throats. The mechanical engineers want to do it gradually, since rapid opening and closing means violent accelerations that bend and break parts, as well as tossing the valves right off the cam profile—the familiar phenomenon of valve float. Obviously, longer valve timings give more time in which to perform the required accelerations and decelerations of the valves; but these, in turn, make the engine dependent on pressure waves in the pipes, and the power curve gets steeper.

Up to the point that the parts are no longer strong enough to take it, stronger springs can be used to control float, but at a cost in cam and tappet wear.

The first choice was obviously overhead cam operation of the valves, since this did away at one stroke with heavy rocker arms and push rods, but this was by itself no guarantee of success. The MV 500 four of this period was a dohc motor of the latest design, but had only a 300 rpm safety band beyond the power peak, so that the rider had to be a genius with the throttle to prevent destructive valve float.

Constant trouble with valve gear no doubt motivated the Honda development team to look for a complete solution that would put these troubles behind them once and for all.

Airflow experts in England had proved that one large inlet valve could flow more air than two smaller ones, for a given cylinder size, so no one bothered about the archaic four-valve-per-cylinder idea any more.

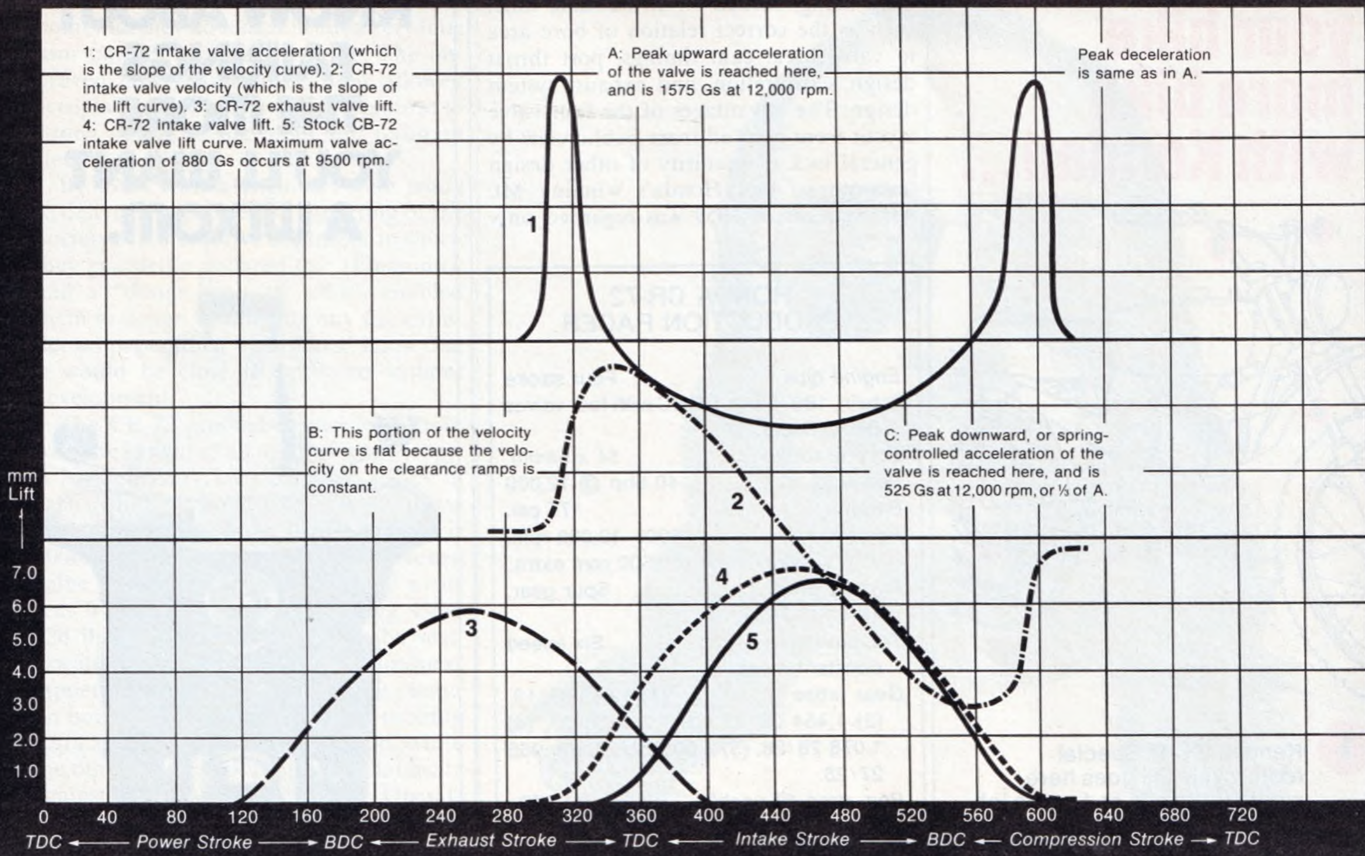
This "proof," however, had come at a time when the chief limit to engine speed was crankshaft bearings and piston rings, so the Honda engineers, already having developed suitable rings and bearings, gave the four-valve idea another look in the light of their new requirements.

It turned out that the reciprocating weight of the two smaller valves was less in proportion to their airflow capacity than that of a single larger valve. A four valve engine might suffer a small loss of breathing efficiency as compared to a highly refined two-valve design, but the extra rpm capability of the four-valve configuration would more than overcome this. The provision of a separate cam lobe and tappet for each valve alleviated the wear problem, so that proportionately heavier springs could be used.

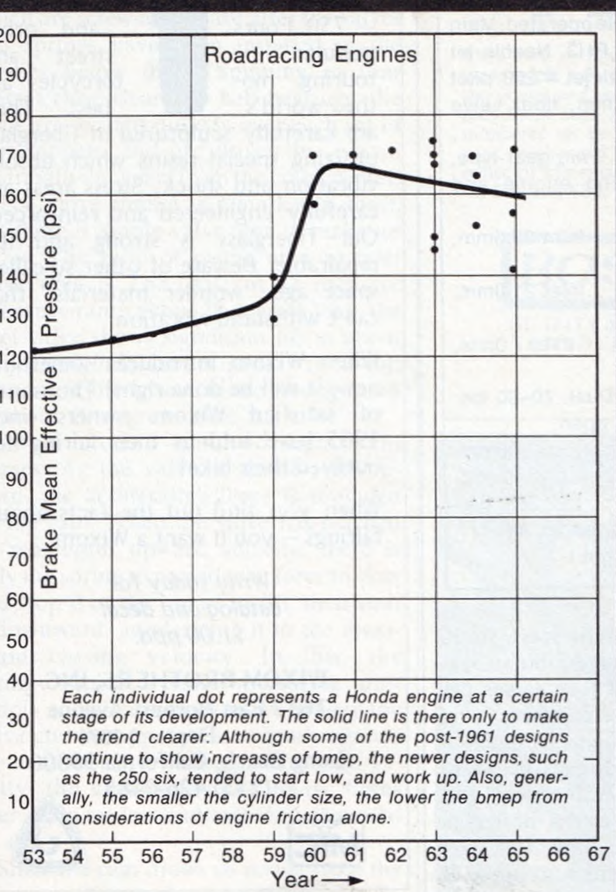
Other benefits appeared along the way. There is no proper place in a two valve head for the spark plug. To equalize flame paths to all parts of the cylinder and so safely use high compression without detonation, the plug must be in the center of the chamber in the way of the valves. The four-valve arrangement, however, has a nice little nest for the plug right in the exact center.

With the improved relationship between flow area and valve weight, the valve stem could be made much longer in proportion to the valve head. This made room for a long valve guide that would permit prolonged operation at high speed without developing excessive clearance, poor valve seating, and leakage. More importantly, it made room for the inlet pipe to make a much more gradual turn as it approached the valve throat. The abrupt turn before the valve is at the heart of many four-stroke engines' low bmep problems, so this one benefit erased the last vestiges of truth from the old "proof" of two valves' superiority to four, and Honda was on its way to its "total solu-

Valve Position, Velocity, and Acceleration

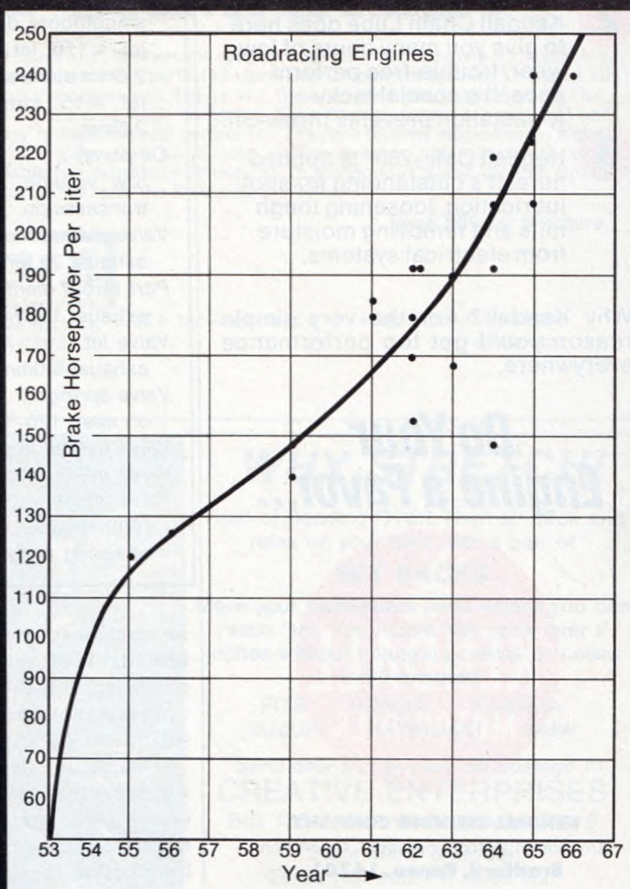


BMEP Development 1953-65



Each individual dot represents a Honda engine at a certain stage of its development. The solid line is there only to make the trend clearer. Although some of the post-1961 designs continue to show increases of bmep, the newer designs, such as the 250 six, tended to start low, and work up. Also, generally, the smaller the cylinder size, the lower the bmep from considerations of engine friction alone.

BHP/Liter Development 1953-67



tion" of the valve gear problem.

Of course, the other engine problems were being worked on at the same time, such as the correct relation of bore area to valve area, cam timings, port throat design, carburetion, and exhaust system design. The advantages of the four-valve layout were masked from public view by general lack of maturity of other design features, so that Honda's winning Mt. Asama racer of 1959 was regarded only as a curiosity in the western press. Its 35 bhp at 14,000 rpm was creditable, it was conceded, but the use of four valves per cylinder showed that the Japanese were still in the dark about engine design.

Two years later, the Hondas began to win repeatedly with four-valve racers and it was clear that the Western designers must be the ones in the dark. It wasn't long before they, too, were working with four valves. At this present day, most

HONDA CR-72 PRODUCTION RACER

Engine type .... Four stroke twin, 180° firing, DOHC with four valves per cylinder.
Bore & stroke .... 54 x 54mm.
Power @ rpm .... 40 bhp @ 12,000
Bmep .... 175 psi.
Powerband .... 8000–12,000 rpm, with a safety zone of 1500 rpm extra.
Primary drive .... Spur gear, 19-63 (3.31:1)
Transmission .... Six speed constant mesh
Gear ratios .... (1) 1.843 35/19, (2) 1.454 32/22, (3) 1.200 30/35, (4) 1.078 28/26, (5) 1.000 27/27, (6) .965 27/28.
Rpm drop @ upshift .... (1) 27%, (2) 21%, (3) 11%, (4) 8%, (5) 4%.
Ignition .... Energy transfer magneto, two sets of points, one sparkplug per cylinder.
Carburetion .... Two Keihin 29mm smoothbore, dual-cable operated. Main jet #110, jet needle RH3, Needle jet 2.6mm airbleed type, air jet #250, pilot jet #55, cutaway 2mm, float valve 2.5mm.
Oil pump .... Twin gear type, low volume, supplying engine and transmission.
Valve diameters .... Inlet 23.6mm, exhaust 22.0mm.
Port throat diameters .... Inlet 21.0mm, exhaust 18.7mm.
Valve lift .... Inlet 7.0mm, exhaust 6.0mm.
Valve springs .... Dual, 70–80 lbs. on seat, 120–130 lbs. open.
Valve overall length .... 100mm.
Valve guide length .... 55mm.
Valve weight .... 26.9 gm. (With retainer, keepers, tappet, and 1/3 of spring weight 79.6 gm.)

serious four-stroke racing engines designed as such use the four valve concept.

Finally Honda refined the design to the point that they no longer needed very long cam timings and large overlap. The improved flow characteristics now allowed acceptably high bmep without recourse to strong tuning of the pipes and resultant steep powerband.

By 1965, Honda engineers were ready to deliver a paper before a meeting of the Society of Automotive Engineers, in which they guardedly declared that Honda now had a "design manual" which enabled them to design confidently any size cylinder on paper, then build it and know that it would be close to optimum without development.

The CR-72 production racer was built with the benefit of all this new knowledge. It has four very long stemmed valves in each cylinder—two 23.6mm inlets and two 22.0mm exhausts. More than half of their 100mm length is supported by bronze valve guides. Each valve is urged to its seat by two nested springs, giving some 120 lbs at full lift, with 75 on the seat. Located above each valve is a cylindrical tappet which, although hollow, is closed on both ends. One end is the flat rubbing surface for the cam lobe to act on, while the other has a small projection that bears against the end of the valve stem. Operating clearance is adjusted by grinding this projection, or by selective assembly, since there are no adjusters to loosen, and no shims to drop out. These tappets are carried in pairs in bronze tappet guide blocks which are screwed in place after the valves and springs have been installed in the cavities below them. Spinning in four special close-clearance ball bearings, the cams are located directly over each set of four tappets, and are driven by a train of straight-cut gears from the crank center.

The valve timing is remarkably short, but there is ample valve area to make up for it. The ratio of piston area to inlet valve area is 2.62. After a 12 inch/sec clearance ramp about 20 degrees long, the inlet valve shows significant lift at about 50 degrees *btdc*, shoots quickly to its full 7.0mm lift, then drops to the closing ramp at about 60 degrees *abdc*.

Valve motion has two significant phases. As the valve is accelerated upward, the accelerating force is provided by the cam. When the valve has reached its maximum upward velocity, there is only the spring to provide the force to slow and stop it at the top of its lift, then start it downward, accelerating it to the maximum closing velocity. In this, the spring-controlled phase, the spring must supply enough excess pressure to keep the valve and its tappet pressed firmly against the cam lobe, preventing valve float. Finally, the cam-controlled phase takes over again to slow and ease the valve onto its seat.

Since the cam draws its power from the

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HONDA CR-72 *Continued from page 75*

engine, while the spring is a fixed value, you can get quickest action without float by using a higher acceleration in the cam-controlled phase than in the spring controlled phase. Usually, this is a ratio of two to one, but in this engine, it is three. The peak acceleration on the cam is 1575 Gs, at peak rpm of 12,000, an incredibly high figure.

A typical maximum acceleration from automotive practice would be 600 Gs, while Mercedes-Benz used 1200 Gs in the design of their desmodromic valve GP car engine of 1954. This, then, is why Honda never bothered with desmo valves; they could get the same results without all the added complexity and bulk.

Feeding the inlet valves through an inlet tract of 255mm total length are a pair of the familiar sand-cast Keihin racing carbs, on rubber mounts. These 29mm instruments are built to stay together, as everything that turns is secured by lockwire or special tabwashers.

The exhaust valves speak into a pair of 520mm long, 35mm ID head pipes that join long, straight-taper megaphones that enlarge to 90mm ID over 760mm. These gradual pipes were a Honda trademark, and are designed to exert a long, mild suction on the combustion chamber over a wide speed range, rather than a powerful and closely tuned one in a narrow range. The engine in fact has a powerband that begins at 8000 and runs to the peak of 12,000, with an 1800 rpm safety limit.

Sparks for the 10mm plug in each cylinder come from an energy transfer magneto. AC from a crank-mounted alternator is switched to the huge Kokusan racing coils by two sets of points whose cam is carried in its own bearings, geared to the crank on the left side of the engine.

The resulting pressure is converted to rotary motion by the exquisite full-skirted pistons and totally machined and polished conrod and crank assembly. Each piston carries two thin gas rings and one oil ring, and the crown is of simple pent-roof shape, matching that of the cylinder head.

Con-rod big-ends are on caged needle bearings, while the crank runs in two ball and two roller bearings.

A straight-cut primary gear pair carries power to the dry clutch, which in turn feeds the very close-ratio six-speed gearbox. This is shifted in conventional manner by a rotating drum and three forks.

Following Honda design practice, both the engine and transmission parts are pressure-fed by the same oil pump, drawing cool oil from a detachable two quart sump located beneath the horizontally split crankcase. The main oil gallery across the bottom of the engine supplies each of the four main bearings and two other oilways. From one pair of mains, oil is picked up to take care of the rods. Oil runs back to twin feeds to the gearbox shafts, and up into the bolted-up block of two cylinders, then tees and enters the head in two places. These two supplies are routed to the tappet guide blocks, lubricating the tappets and cam lobes. Splash takes care of the cam bearings, while returning oil flows downwards over the valve springs, cooling them before entering the central gear tower for the long drop back to the sump below. On the way, the oil must pass through small sieves, whose purpose is to trap the debris of any cylinderhead disasters so it can't get into the rest of the engine.

This is a lot of machinery, and the weight of this engine is considerable at 132 pounds, which is four pounds more than the four cylinder GP engine of the same period. Other Honda racers were much more successful, which is to be expected, since the CR's were a compromise between performance and simplicity, while the championship machines were built to win without regard for price.

However, the CR-72 and its more famous brothers were built on the same basis of engineering innovations and design philosophy; set the bmep at a level that guarantees a flat torque curve without "tuning bumps" through the use of advanced valve gear, then select the number of cylinders that will permit the rpm necessary with that bmep to give competitive horsepower.

The CR-72, and indeed all of the four-stroke racers Honda built in the 1960s are ready for the museums now, but they have left their mark, not only in the record books, but on current practice in high-output engine design. Then, too, they've left their mark on each of us who followed them through their career at a magazine's distance, or close enough to hear the unearthly "Whoop-whoop-whoop" of the six warming up, or to see Mike Hailwood show his posterior to the competition.

As the rumors of new Honda participation in roadracing increase for the n-th time, I really want to see it happen. If and when it comes about, the machines will be full of new thought, whether two-stroke or four (or other), because they are very clever people at Honda. They hire only "A" engineers. And it will be fun. ◉