Desmodromics

Mick Walker explains how Ducati beat the world with spring-less valve operation

THE WORD *desmodromic* will not be found in the Oxford or any other English dictionaries. It was coined from two Greek words, meaning 'controlled run' and its mechanical function is to eliminate one of the phenomenon of valve float, or 'bounce'. This happens at high revs when the valve springs are unable to respond quickly enough to close the valve back on their seats. The desmodromic idea was to replace troublesome springs with a mechanical closing system much like that used to open them.

Eliminate the springs and you eliminate the bounce and get a higher-revving engine – in theory.

This had been known since the early days of the internal combustion engine but for many years no designer managed to successfully harness it. One of the first examples of completely positive mechanical valve operation was used by the French Delage concern in its grand prix car of 1914 – and the French knew the method as *desmodromique*.

The Delage engine employed four valves per cylinder in pent-roof combustion chambers. Twin overhead camshafts were used and each valve pair was actuated through a stirrup-shaped tappet with an integral, duplex bridge-piece at its lower end. Two cams were used: one depressed the tappet to open the valve via the upper member of the bridge, the second cam raised the tappet to close the valve through the medium of the lower bridge member. Between this last item and a collar on the valve stem a small 'tolerance spring' was interposed to ensure that the valve was pulled positively on to its seat. It would not have been possible to manufacture sufficiently accurately then to provide positive seating without some degree of freedom.

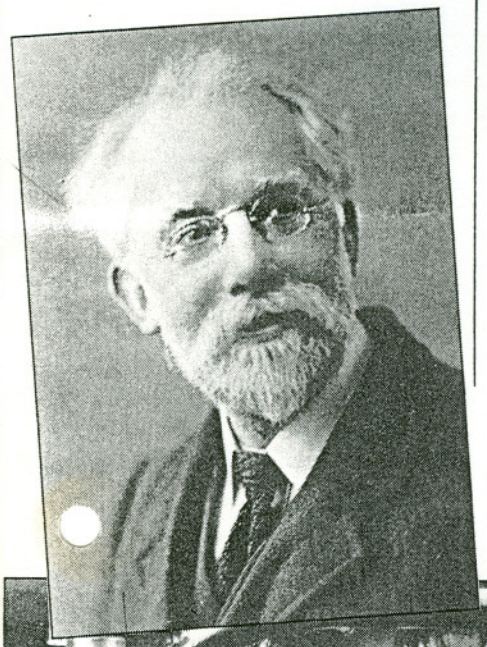
The Delage system was not particularly successful and was not developed, but in the 1920s several other manufacturers tried variants of it. One layout, the Vagova, utilized a cam track embodying inner and outer cam forms which guided a roller attached to one end of a 'rocker', the other end of the rocker was forked to embrace the valve stem. To provide the required freedom for seating, the pivot of the rocker was given a small amount of spring-loaded float parallel to the valve axis.

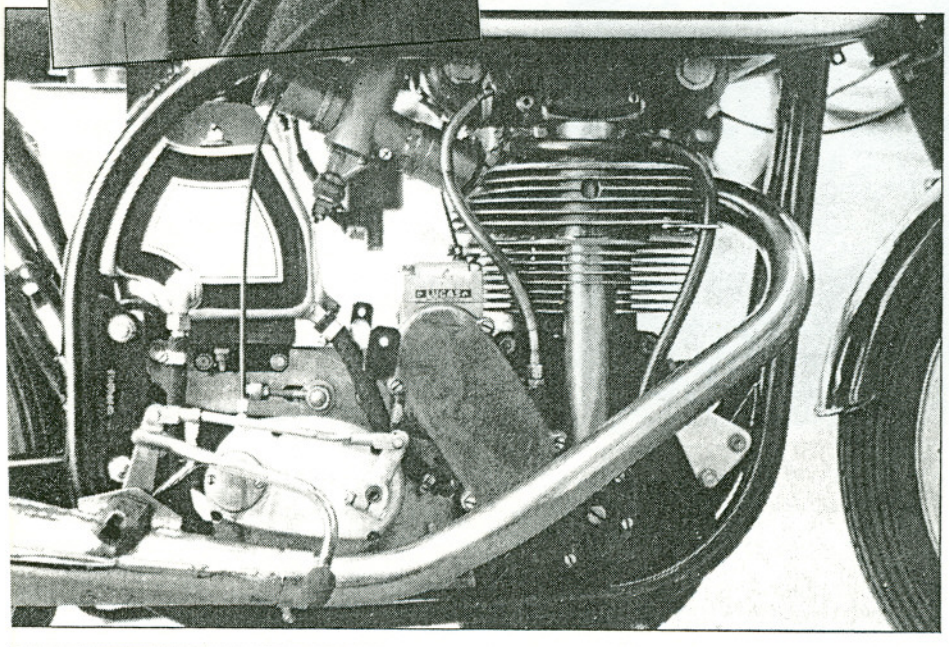
Alternative methods investigated were to use the cam track in conjunction with a tappet for direction operation of the valve, or to retain the rocker but incorporate two cams, one bearing on each end of the rocker. A more complicated version was that used by Bignan-Sport, also during the twenties. It featured a bevel-gear driven face cam or swash plate provided with a vee-section periphery. Motion was conveyed from cam to valve by a crosshead running on a guide; the crosshead carried a pair of oppositely inclined rollers, one of which ran on each face of the swash-plate periphery.

In Britain another form of desmodromic operation was patented in the early 1920s by none other than the legendary James L Norton, founder of perhaps the greatest name in British motorcycling. This was similar to the Vagova design in that it employed a cam track and rocker. However, instead of Vagova's spring loaded rocker trunnion the Norton rocker end entered a slot in the valve stem and a small leaf spring was fitted on the rocker's upper surface. Complete closure was ensured by the provision of an adjustable abutment in the valve stem above the rocker. Ingenious, but one cannot visualize slotted valves standing up to todays thermal and mechanical stresses.

A complex variation of the Bignan-Sport face cam theme was patented by the car giants Fiat, also in the late 1920s. A spring loaded crosshead was mounted on the valve stem; at each end of the crosshead was a roller, and the rollers ran between a pair of faced cams mounted coaxially with the valve and driven by spur gears. The direction of rotation of the rollers would, of course, be suddenly reversed as they transferred from the opening to the closing face cam, so that the rate of wear of the mechanism might well be high.

The double cam layout has had many adherents in the past. In 1916 J M Brewster invented an overhead valve arrangement operated by rods. The opening cam was followed by a roller ended tappet connected to the valve opening rocker by a jointed





James L Norton – the great British designer conceived his version of the positive valve operation in the late 1920's.

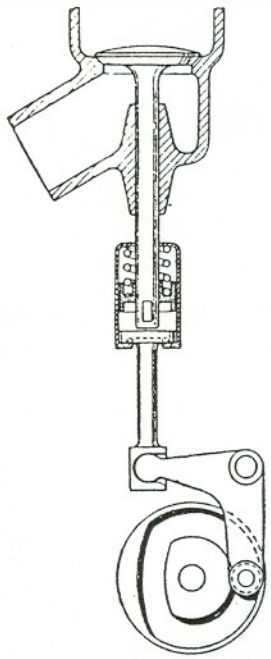
push-pull rod. On the tappet was a transverse peg engaging with the forked end of one arm of a bell crank lever. The other arm of the bell crank carried a second roller which bore on the closing cam. But this layout included more pivots and arms than would appear desirable, though it would probably have worked well enough at the low engine speeds of the day.

A spring loaded trunnion appeared also in the Vareille design in which, instead of the cam track as on the Vagona, there were two cams between which the rocker end was sandwiched. A shackle connected the rocker's other end to the valve stem. Technically, though, it would have been more practical to have had a forked rocker end and abutments on the valve; otherwise the Vareille system was robust and simple – even by present day standards.

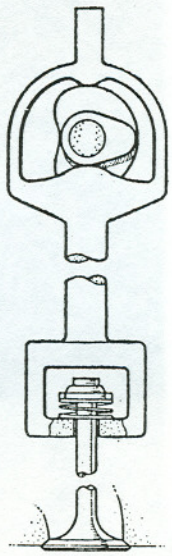
But one of the neatest and most sensible of the early designs – and which was similar to what both Mercedes and Ducati used years later, came from Ballot, a name once well known in French motoring circles during the veteran and early vintage period. This comprised a double cam and three arm rocker of Y form. One arm bore on the opening cam, the second on the closing cam and a third had a forked end which actuated the valve through abutments. Complete closure was ensured either through a spring above the fork or by allowing some spring controlled movement between the two cam follower arms of the rocker.

One of the last designs to appear prior to the onset of the barren years for desmodromics (1930-54) was the work of G A Mangoletsi, then a well known sand racer from Southport and later head of the G M Carburettor Company in the 1950s. Not unlike the Ballot valve gear, Mangoletsi's scheme was even simpler in that the follower of the closing cam was embodied in the valve actuating arm. The opening cam follower ran on the same pivot as the arm, and a spring between the two components compensated for cam irregularities of manufacture or wear.

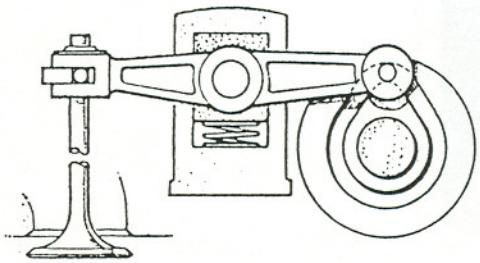
Valve position was set relative to the rocker arm by means of adjustable collars on a threaded valve stem. Spring washers between the collars and rocker abutments provided a degree of freedom to ensure complete closure.



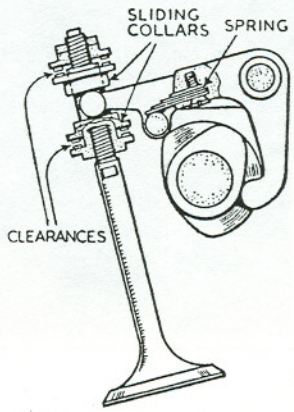
The granddaddy of all desmodromic systems, F H Arnott's valve mechanism was patented in 1910. It incorporated a cam track, a bell crank lever and a tappet.



1914 French Delage employed a desmodromic layout of two cams and a stirrup member; each stirrup operated two valves.



Vagova utilized a cam track and rocker; the rocker trunnion was spring loaded to ensure complete rocker closure.



The Mangoletsi system used a leaf spring to take up any irregularities between the profiles of the two cams.

ALL THE activities in the 1920s might suggest that, apart from Brewster and Delage, no one had done anything earlier on positive closure. However, that was not the case, because as far back as 1910, English engineer F H Arnott provisionally patented the grandaddy of all desmodromic valve operations. The Arnott design employed a cam track and a bell crank lever, also a small clearance between the cam follower and valve, and a closing spring – a formula subsequently utilized in varying degrees by other designer. In comparison with Vagova and Norton, the Arnott valve lay on the other side of its rocker arm, so that the cam track had the same form as the *closing* cam of a twin cam layout, instead of that of the opening cam.

It is interesting to recall that years later Arnott revived his interest in motorcycle engines with the advent of 500cc car racing in the early 1950's. He remembered his old patent and decided to try his hand once more at desmodromics with the conversion of a 500cc JAP ohv single in 1954. However, this later Arnott design differed considerably from the original and was reminiscent to the Ballot and Mangoletsi methods. There were two cams and a Y shaped rocker having a forked leg bearing on collars on the valve stem. The rocker, unlike that of the two earlier inventions, had no spring loaded tolerance and Arnott stated at the time that, with the design and materials employed, no valve seating difficulties were experienced with his 1950s JAP engine. And Arnott's statement in 1954 coincided with the re-birth of desmodromics (and that the introduction of springs into a device intended to eliminate them had been an unnecessary complication which hampered development and was without

doubt the reason it is not in wider use today).

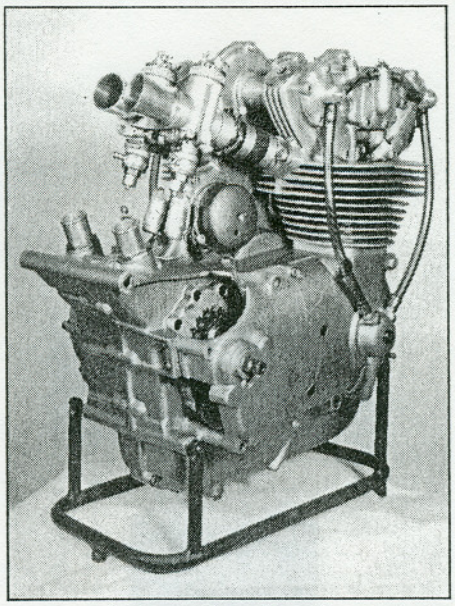
Interest in desmodromic valve operation waned until in the immediate post-war days it had almost been forgotten when in 1954 the giant Mercedes Benz concern decided that something better than spring return was required for its new W196 2½ litre grand prix engine. The German company therefore evolved a desmodromic layout, the success of which was evident if one consults the car's 1954 racing record. The unsupercharged, straight-eight cylinder engine was reputed to develop over 260bhp (or 104bhp per litre). With an individual cylinder capacity of 312cc it is easier to see that this design was still of interest to the motorcycle world.

Two cams per valve were used by Mercedes (as on the Delage engine), and each cam had its own rocker. The rockers were pivoted side-by-side on a common shaft and had a scissors disposition. The opening rocker bore on a shoulder part way down the valve stem, and the closing rocker on a collar near the end of the stem.

Originally the design embodied final closure of the valves by springs, but the springs were dispensed with after tests had revealed them to be unnecessary. All that was required was an ultra small clearance and pressure inside the cylinder did the rest. Thus simply was one of the original problems overcome!

Whereas the cam track principal described earlier is easy to understand, the double cam arrangement requires a brief explanation.

The opening cam is of conventional form, while the closing cam is, in effect, an inversion of the opener: it begins to drop from its base circle when the opening cam lifts from its base circle; the peak on the opener coincides with the lowest point on the closer, and the closer lifts from its lowest point as the opener comes off its open dwell on to the return flank.



Ducati 250 desmodromic twin specially commissioned by Stan Hailwood, for his son Mike to race in 1960.

Left: Bruno Spaggiari (desmo single) leads Mike Hailwood (desmo twin), during practice for 1959 125cc TT.

Besides Mercedes the motorcycle sphere had also seen several designers show a distinct interest in desmodromic valve operation around that time, most notably Joe Craig, (race supremo at Norton in the early 1950s) and more significantly in the Desmo story, Ing. Fabio Taglioni. Ing. stands for *Ingegnere*, the Italian for engineer. In a country with as proud an engineering heritage as Italy, its a title which commands respect and its men like Taglioni who made it so. And, unlike Craig, Taglioni was able to launch his ideas from the drawing board into hard metal.

In the late 1940s, whilst studying as a young man at Bologna University, Taglioni had first put pen to paper to conceive his initial motorcycle engine designs which included desmodromics and a 90 degree, L shaped V-four 250!

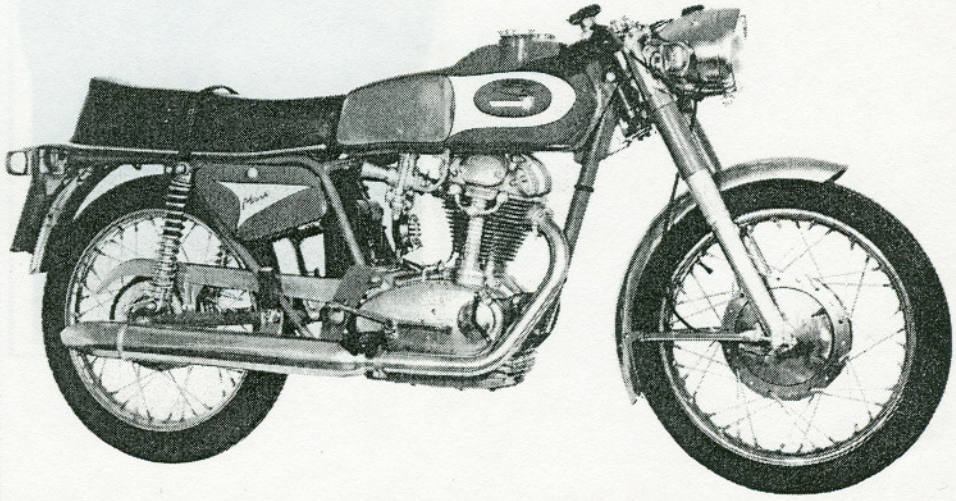
Taglioni worked for F B Mondial during the early 1950s upon graduating from University. At that time Mondial were one of the most successful marques in Grand Prix racing. And as they specialized in the lightweight classics this meant specializing in the problems associated with high engine revolutions. It was during this period that Taglioni first tried to exploit the potential for desmodromics. However, it was not until he joined Ducati in early 1955, that he was able to develop many of his ideas through to fruition – including positive valve closure.

It was this year that saw Ducati's first serious attempts at road racing; up to Taglioni's arrival, the works had converted standard machines to take part in local events, which, for the most part, meant either trials or long distance road races.

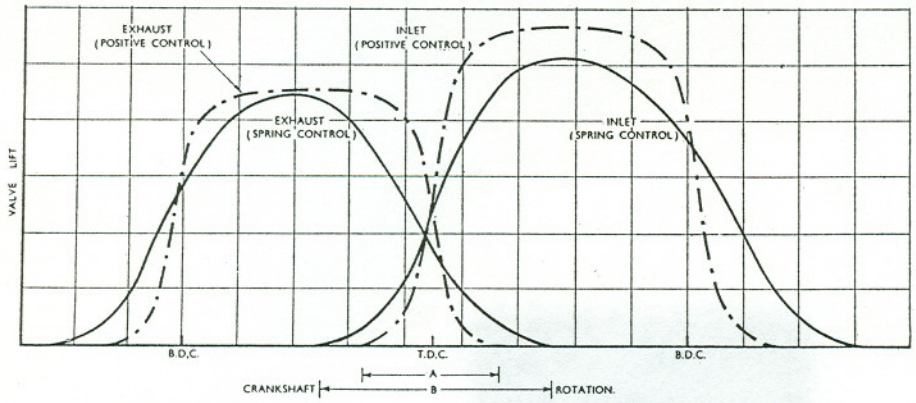
TAGLIONI'S first design for his new employers was a 98cc single overhead cam model, the 100 Gran Sport. This sports roadster-cum-racer was soon the most popular in its class for the long distances road races of the day and helped to launch the careers of such acclaimed riders as Spaggiari, Pagani, Francesco Villa, Gandossi Farne and Mandolini.

But the Gran Sport project had not been conceived purely as an over-the-counter racer. It was to be the spark which inspired not only the company's range of single cylinder roadsters for the next two decades, but also the base for a full scale venture into Grand Prix racing. For the early racing, Taglioni first produced a dohc version of the Gran Sport, enlarged to 124cc (55.25 x 52mm). Except for a complete new cylinder head assembly, a truly massive casting which housed the complex valve gear, and five speed gearbox, it was virtually identical to the original design. But although this proved reliable it was not *quite* fast enough to challenge the class leaders MV Agusta.

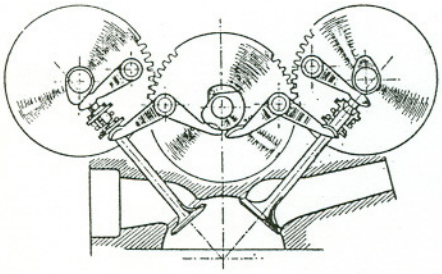
Enter Taglioni's first desmodromic design to turn wheels. This used the same 55.25 x 52mm bore and stroke, ran on a



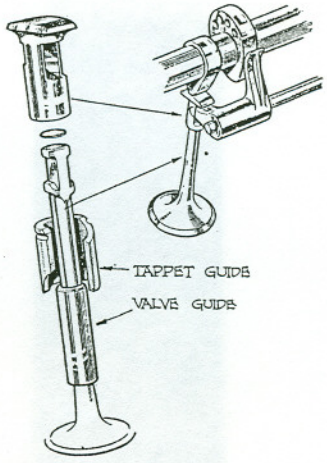
World's first production motorcycle with desmodromic valve operation, the 1968 250/350 Ducati Mark 3D (D denoting Desmo).



Theoretical valve diagram for the desmodromic valve layout compared with that of an orthodox spring controlled system. A and B represent the respective amounts of overlap.



In the original system used Ing Taglioni in the 1956 125 Ducati desmodromic single cylinder GP racer, the lever type rockers absorbed cam loads and the axes of the valves stems and cams were offset to secure maximum mechanical advantage.



Desmodromic valve gear on the Mercedes W196 racing car engine, circa 1954.

compression ratio of 10.5:1 and used a titanium con-rod that was double webbed at top and bottom to withstand the stresses of substained high evolutions.

The chief problem Taglioni faced convinced him of the need to use desmodromics – the increasing vulnerability of orthodox valve gear to overrevving. Quite simply, higher maximum revs inevitably meant an extension of valve timings and wider overlap periods around tdc. In addition larger valves meant less clearance between them during overlap. Despite the use of dohc to reduce reciprocating weight, a brief bout of over-revving, however caused, spelled disaster, with the tiny clearance found on a high revving ultra lightweight class engine proving insufficient and the inevitable result of the valves kissing. Meanwhile increasingly high compression ratios meant less valve-to-piston tolerance, and a rising piston could then overtake a floating exhaust valve. Either way the engine was damaged and the race lost.

Taglioni's solution was to dispense with valve springs and use the cams to close the valves, assisted by additional rockers. And unlike the majority of earlier designers Taglioni had not been tempted to use some form of spring in the system. The only disadvantage (which he openly admitted) was in the event of a piece of grit, however small, getting trapped under the valve seat. But the risk was one Taglioni preferred to take in his quest for maximum performance.

In its conversion from dohc to desmo the 1956 Ducati 125 racer gained 3bhp (19bhp at 12500rpm against 16bhp at 12000rpm).

Prior to the desmo's debut came a long period of exhaustive factory tests. Taglioni wanted his baby right first time. Experimental engines had been run on the test bench for up to 100 hours at full throttle! Meanwhile, on the track testers had hurtled around sometimes exceeding 15000rpm with no ill effects – unheard of at the time.

With a profound confidence in the new machines speed and ability to keep going, the factory readied the racer for its first competitive outing.

THEY picked the 1956 Swedish GP at Hedemora, which although a non championship event at the time, still nonetheless had attracted a top class entry.

However, as soon as Antoni started to warm up his engine, onlookers *knew* that here was something special. This newcomer sounded deep, mellow and powerful. It was a suspicion that was confirmed in the first practice session, when the engine note rose to an intense wail like an angry wasp as the machine swept around the circuit. Once the race started, Antoni showed just how superb the desmo single really was, setting the fastest lap, lapping every other rider at least once and finally finishing the race in record time.

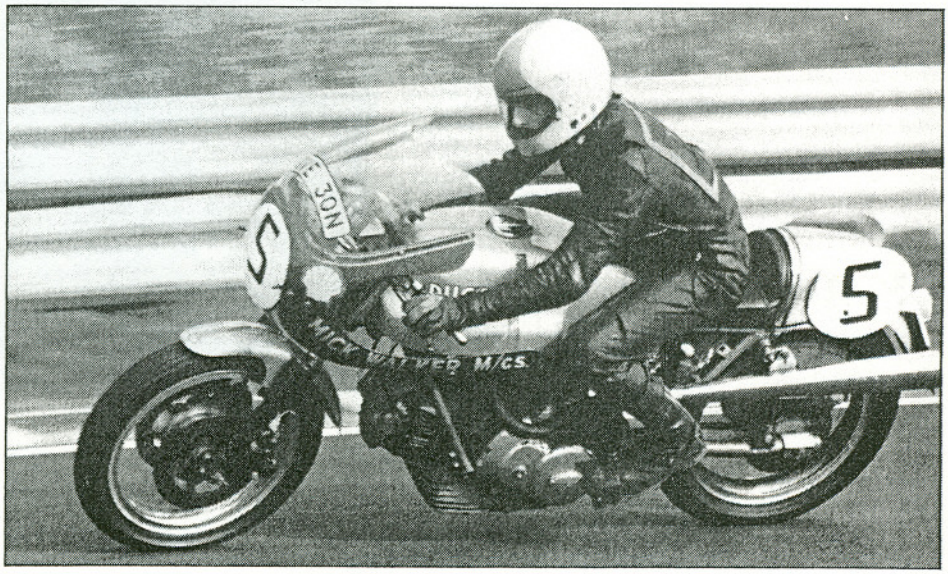
How many other factories have had such a Grand Prix debut, or such a foundation on which to build a legend. . . .

But along the way there were to be many pitfalls and heartaches before the word desmodromic was to become an accepted part of the everyday motorcycling vocabulary.

Following his historical Swedish GP victory, Antoni had returned home to Italy with the winning desmo prototype. But unknown to him and Ducati disaster was just around the corner. In his very hour of glory, with the prestigious Italian round of the world championship at Monza, Antoni took his 125 desmo out for a test session at the circuit. Tragically, he crashed on the Lesmo Curve and died from his injuries.

Antoni's death effectively stopped Taglioni and Ducati in their tracks and a whole year and more was to pass before Ducati were once again ready to mount a challenge for Grand Prix honours.

This came at the first round of the 1958 125cc World Championship – the Isle of Man TT. For this Ducati fielded four riders, Romolo Ferri, Luigi Taveri, Dave Chadwick and Sammy Miller – all competent competitors, but not in the class of the two MV pilots, Carlo Ubbiali and Tarquinio Provini.



1974 Ducati 750 SS – equally effective on road or track.

Even so desmodromic Ducatis took second, third and fourth places in the race.

Even better was to come. The next round, the Belgian GP, was held over the super fast Spa Francorchamps circuit. Here speed, rather than riding ability was the prime requirement and the Bologna desmos clearly demonstrated their potential by taking first, second, fourth and sixth places with world champion Ubbiali relegated to fifth spot!

And it is generally accepted that if Ducati's leading rider Alberto Gandossi (who had not ridden in the Isle of Man) had not fallen in Ulster, he, rather than Ubbiali, would have been champion at the season's end. The final found at Monza had seen the mighty MV s annihilated, with Ducati taking the first *five* places. A brand new prototype twin cylinder model finished third.

Unfortunately just when Taglioni's brain child seemed likely to totally dominate the ultra lightweight racing category, a change in factory policy meant only limited participation the following season. Even so an 18-year-old youngster named Mike Hailwood had his first GP victory (at the Ulster GP) on a desmo single that year.

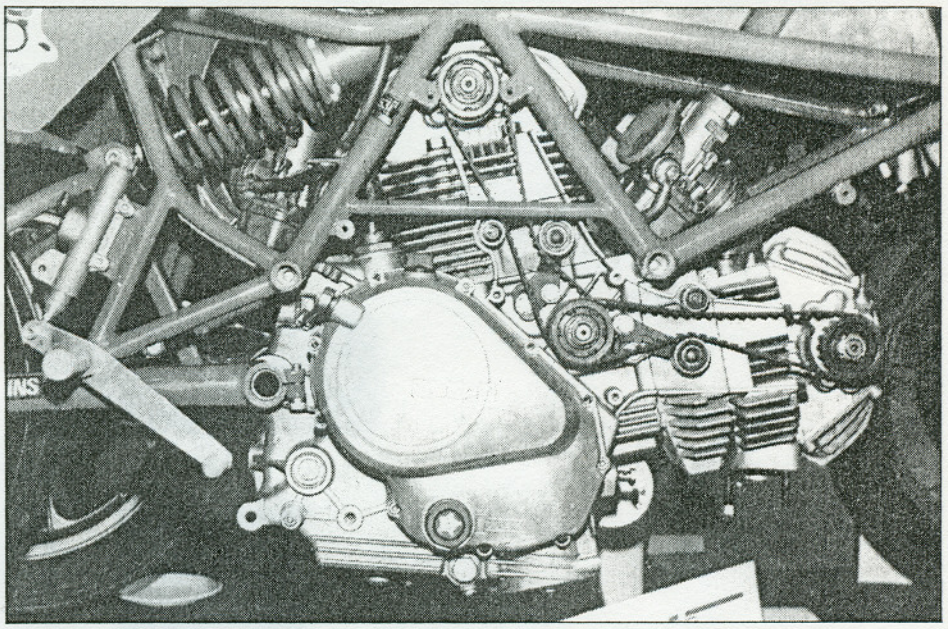
Stan Hailwood, Mike's father, had been so impressed with the desmo's performance during 1958 that he bought Mike a couple of works 125 desmo singles, and even commissioned 250 and 350 twin cylinder versions. These latter two designs would no doubt have had a better chance of repeating the single desmos success had they been developed by the factory, rather than being purchased, largely untested, by the Hailwood equipe.

During the period 1958 to 1961 many others tried unsuccessfully, to emulate Taglioni's success. Firstly, Mondial would most likely have raced a desmodromic 250 in 1958 had they continued racing. Benelli experimented but gave up. A desmodromic version of the Manx Norton was built, but this was not proceeded with. Even private concerns, such as Velocette specialists BMG of Ilford, Essex, converted a 500 from to desmodromic valve operation, but none were anywhere as successful as Ducati.

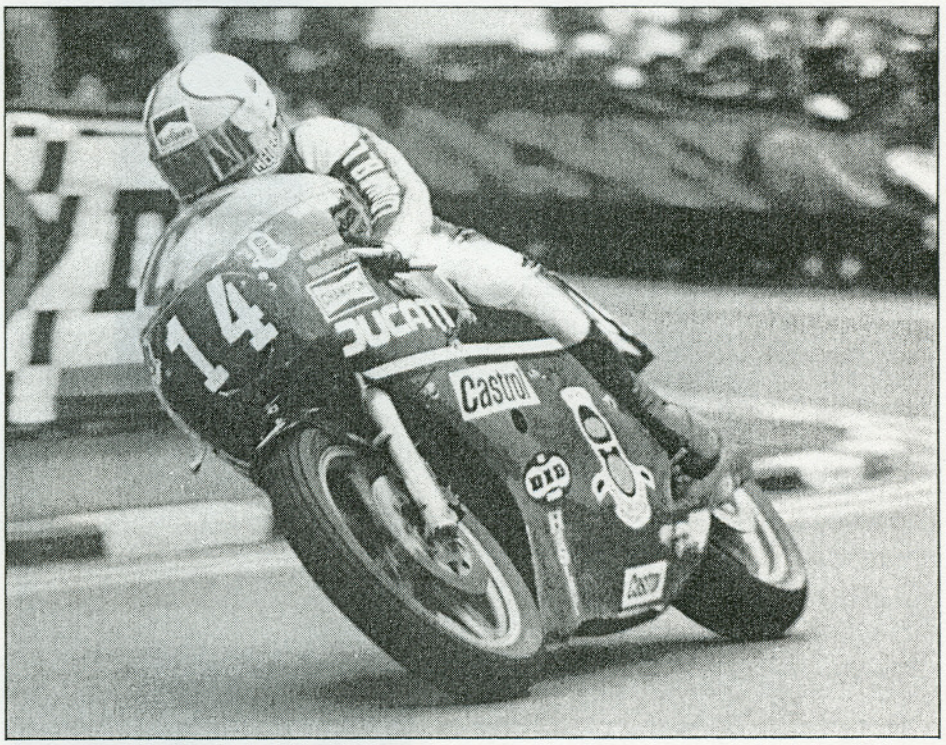
But probably Taglioni's crowning glory came in 1968 with the introduction of the first mass production motorcycle (or for that matter vehicle), with desmodromic valve operation.

For a man who believed that the simple things were usually the best, the newcomers were eactly the same as their Mark 3 ohc brothers from the cylinder barrel downwards. The mechanical operation for valve opening and closing was similar (although with only one camshaft) to the type that Taglioni had devised for his earlier desmo racing machines. The main difference was that in the roadsters the valve closing was assisted by springs, unlike the racers.

However, the springs used were very much lighter than the ones on non-desmo models (in fact, they were from the 125/160 roadsters). And as proof of Ing. Taglioni's simply-is-best-approach, many of the cylinder head's less critical components were borrowed from existing production models giving both Taglioni's production staff and potential owners a far easier time when spares were needed.



New generation of Ducati desmodromic engines featured belt driven cams, known as the Pantah. These entered production in the late 1970's. Today every motorcycle offered by the factory is a belt driven desmo model.



Cementing the legend, Mike Hailwood returned to Ducatis – and the Isle of Man – to create a sensation by winning the 1978 Formula I TT.

Compared with the valve spring engines valve seat pressure of 80lb/square inch, the desmo was 8lb/square inch making kickstarting easier and giving much less seat wear – both important advantages for road-going units.

Amazingly the only *real* difference between the standard valve spring Mark 3 and Desmo engine was, that the latter had four rockers (in place of two on the Mark 3) and a four lobe camshaft, in place of two. Even the valve head diameter and materials were identical but the method of valve stem collect retention was different!

The commercial success of the single cylinder desmo roadsters meant that when the factory introduced its V-twin range in the early 1970's it was not long before desmo versions of these too began to appear.

BY 1980 *all* Ducati production motorcycles had desmodromic valve operation and this is the picture today, with Ducati, now owned by Cagiva, still exclusively marketing a range of bikes with one feature which no other producer in the world offers – and that magical word DESMO. This sales success is surely lasting proof of an idea which had its roots firmly in the veteran and vintage days of motorcycling, but even today is viewed by many as being amongst the very vanguard of two wheel progress – a rare achievement indeed.