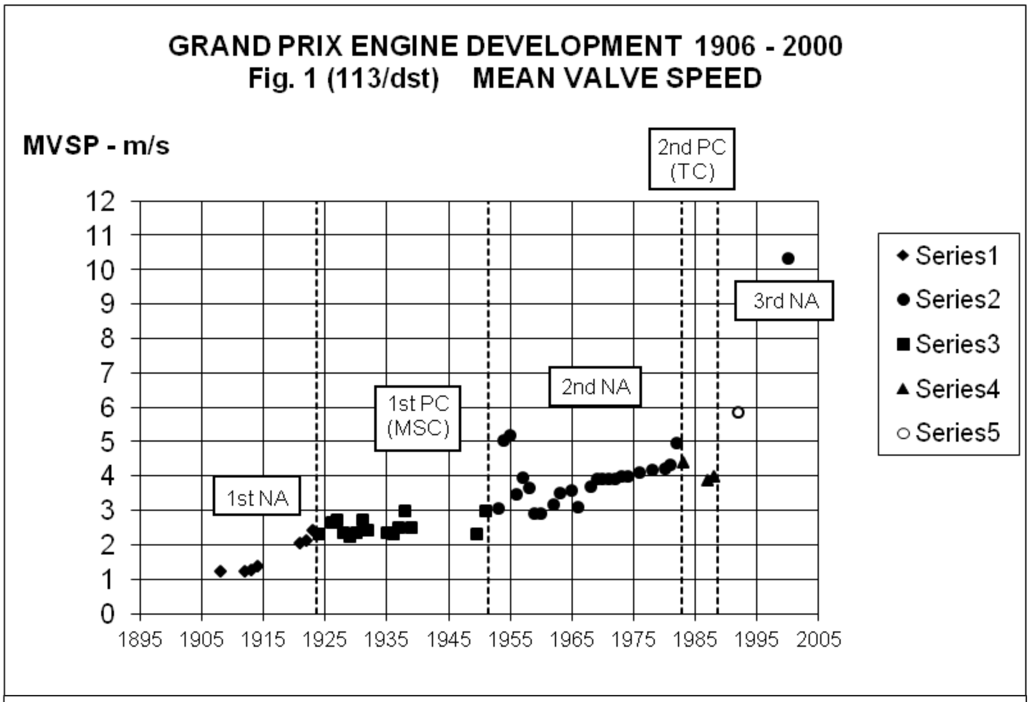
Note 15

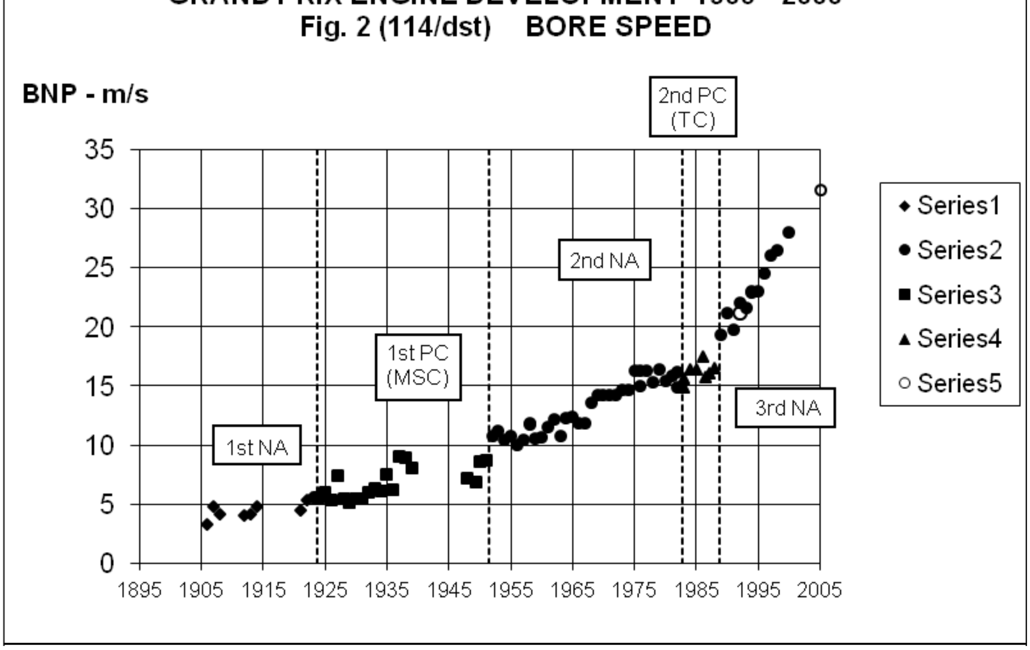
Valve-Spring problems and their solution

Note 13 Part III describes the general theory underlying valve gear, with the parameter Mean Valve Speed (MVS: MVSP at Power Peak RPM NP) of considerable importance. As a surrogate, since the Inlet Valve Lift (IVL) and Inlet Opening Duration (IOD) elements of MVSP are often unavailable, Bore Speed (BNP) can be used since this is dependent approximately on the same material and gear design parameters.

Until 1990 it can be taken that nearly all valve gears had cam-opening with a steel wire Coil Valve-Spring Return System (CVRS), with a few exceptions which will be identified below.

Figs. 1 and 2 illustrate the variation of MVSP and BNP, respectively, over the review period for CoY engines (the definitions of MVSP and BNP are given below).





MVSP = (IVLmm x NP RPM)/(83.333 x IOD^0) m/s; BNP = (Bmm x NP RPM)/60,000 m/s.

Pre-WW1: similarity of BNP

Sub-Note A extends the Fig. 2 data for BNP to a variety of other pre-WW1 racing engines of very different types of Overhead Valve (OHV) gear. It seems very clear from the table that it was BNP which was controlling engine speed at that time, varying from a 10 sample average of 4.1 m/s by +17% to -13%, a range from lowest to highest of x1.34. By contrast, Mean Piston Speed (MPSP) is shown to range from 7.3 m/s to 17.0, i.e. x 2.33

The similarity of BNP over 9 years of pre-WW1 OHV engine development of such disparate types is due presumably to problems caused by the crude cam shapes and the low fatigue life of the spring materials of the time. The Henri-designed Peugeot Double Overhead Camshaft (DOHC) designs, although *fundamentally* the "Way-to-Go" – by minimising valve gear inertia – nevertheless did not then represent an advance in MVSP. Specifically, his 1914 engine did not reach the same BNP as the rival Mercedes Single Overhead Camshaft (SOHC).

Where known for this period, MVSP was around 1.3 m/s.

Overhead Camshafts post 1912

Post the 1912 Peugeot introduction of DOHC all CoY engines were either built to that system or SOHC, with the single exception of the 1936 Auto Union (Eg. 22) which had Push-Rod Operated OHV (PROHV) for its exhaust valves (and a consequent inability to over-rev for a passing opportunity (607)); SOHC nearly disappeared in 1931 when Bugatti (via Miller) finally saw the light with the T51 (Eg. 17), except for the Australian Repco engines of 1966-1967 (Egs. 45 and 46).

Inter-War MVSP improvements

Post-WW1 there was a rapid increase in MVSP to around double the pre-WW1 level. Increased understanding of cam profile effects and of spring design produced this improvement. For example, the 1921 Duesenberg IL8 3 L (Eg. 7) used to break springs at MVSP = 2.1 m/s until Elbert Hall (involved during the war with the "Liberty" aero-engine design) redesigned the cams (6). Not only were the failures overcome but there was also a 16% power increase from the higher RPM tolerable.

The early '20s FIATs (Eg.8 1922 IL6 2 L) also, although very successful, suffered many spring failures (25). They had triple concentric springs to guard against this causing a valve to drop into a cylinder (4). When Vittorio Jano moved from FIAT to Alfa Romeo to design the 1924 P2 IL8 2 L (Eg. 10) he found that the way to prevent the spring surge which was causing the failures was to wind the coil springs with fewer turns of thicker wire ("surge" being the undamped resonant vibration of the middle moving mass of the coils). This raised the spring natural frequency.

Outside Grand Prix racing, Rolls-Royce found that when they uprated the RPM of their 1929 R-type Schneider Trophy-winning engine by 10% in 1931, to about MVSP = 2.6 m/s, they also ran into surge failures and they solved them as Jano had done. They described the resultant spring design as "somewhat reactionary" (1015)!

This MVSP around 2.6 m/s was about the level reached reliably by GP engines before WW2. The 1938 Mercedes M154 60^0V12 3 L (Eg. 24) reached 3.0 only after a great deal of experimentation with the gear and it was reduced to 2.5 m/s in the 1939 M163 (Eg. 25) when the engine was run more slowly (possible with 2-stage Roots supercharging) and IOD was increased (468).

Pre-WW2 Hairpin Valve-Spring Return System (HVRS)

The Hairpin Valve-Spring Return System (HVRS) was pioneered by a Sunbeam motorcycle in 1925, and by the '30s most British racing motor-cycle engines had changed over from CVRS to HVRS. In this system the spring material is in tension instead of torsion to obtain freedom from surge and it also provides isolation of the spring from the hot valve stem (the hairpins were often exposed to the cooling airstream as well). The springs were much more expensive, having to be hand-made instead of machine-wound and they were also much bulkier. The 1938 Norton 1 cylinder 500cc aircooled TT-winning engine with DOHC (SO12) had MVSP = 3.1 m/s and BNP= 9.2 m/s

Post-War HVRS

When Gioachino Colombo designed 60^0V12 engines for Enzo Ferrari immediately after WW2 he accepted the advantages of HVRS over CVRS, as the latter then existed. However, the level of MVSP reached, even by his late-1949 DOHC-redesigned 60^0V12 1.5 L (Eg. 27) was only 2.3 m/s. The engine RPM were restricted by breathing so the extra expense of HVRS was unjustified. When Aurelio Lampredi also used it for the Naturally-Aspirated Ferrari type 500 IL4 2 L of 1952 – 1953 (Egs. 30, 31), MVSP was pushed up to 3 m/s, i.e. the same as the 1938 Norton of identical individual cylinder capacity. These Ferraris were the last-but-one CoY to use HVRS. Two Grand Prix engines designed originally in 1953 with HVRS, the 90^0V8 2.5 L units of the Lancia D50 and the Coventry Climax FPE were both re-designed to CVRS.

Desmodromic Valve Return System (DVRS)

In 1953 Mercedes-Benz adopted "Desmodromic" , mechanically-closed, valves for their new M196 IL8 2.5 L engine (Eg. 32), the 1st DVRS since Delage tried it without success in 1914 (see Sub-Note B). It was mainly to secure protection against valve-to-piston collisions if/when oversped in the heat of battle but also to obtain sufficient opening area to produce over 100HP/L while retaining IOD of only 256^0 to assist flexibility. This DVRS reached over 5 m/s (468). The problem of differential thermal expansion, which had defeated all previous DVRS designs, was solved serendipititiously by leaving a small clearance between valve and seat to be closed by charge compression pressure. Cost was high, which was not a problem for Mercedes but probably was a reason why only one subsequent GP engine ever raced with DVRS, the American IL4 2.5 L Scarab copied from the M196, and it was unsuccessful (see Sub-Note B). Many other companies did experiment with the system, including Cosworth in the mid '70s. The Ducati motor-cycle racing engines were fitted with DVRS successfully by Fabio Taglioni in 1958 and that firm have retained it ever since for both racing and production engines but they are also unique in their sphere.

Improved CVRS

The coil valve spring received a boost in fatigue life in the mid 1950s from the availability of Swedish wire of very high material purity, i.e. less slag inclusion. The process of shot-peening was also added to provide a compressive anti-fatigue surface layer. This wire spelt the end of HVRS where it had been adopted, eg in Ferraris from 1946 to 1955. The last CoY HVRS was the 1958 Constructors' Champion Vanwall IL4 2.5 L, which was a carry-over from its Norton "Top End" origin. Having also used HVRS from 1947 in their 135^0V16 1.5 L, BRM – unfortunately very far from CoY – finally converted their IL4 2.5 L to CVRS in mid-1960.

Torsion-bar springs

An exception to both systems, also non-CoY, was the 1966 Honda 90^0V12 3 L which used torsion-bar springs, i.e. directly not coiled. Although unsuccessful in GPs, the Honda IL4 1.0 L Formula 2 engine with the same feature was nearly unbeatable in 1966.

Double Coil Springs with interference fit

Another step forward for CVRS in the mid-'60s was the adoption of selectively-fitted interference between outer and inner springs – dual springs having long been used but with no touching of the coils. This provided damping to reduce surge amplitude. Rolls-Royce used this idea in their 1964 IL6 4.0 L FB60 engine for the BMC "Princess" (865). The Ford "Four Cam" Indy 90^0V8 4.2 L engine (SO17) was so assembled in 1965 (864) with MVSP = 3.8 m/s and the Cosworth DFV 90^0V8 3 L DFV (Eg. 47) was a notable user of the principle some years later. Because of the inevitable wear reducing the damping with running the method was restricted in high-speed engines to short life and was therefore not suitable, eg, for Le Mans 24 Hours (16) (the pioneering FB60 was of course not a high-speed engine and also the inner spring was flat section to reduce wear). In Grand Prix racing the springs had to be replaced after every event (59).

Cosworth DFV development

Although held back for 3 years by a valve-drive resonance, at the end of its development in 1982 the Cosworth DFV had reached MVSP = 4.3 m/s typically but up to 5 m/s when care was taken to avoid overspeeding (Eg. 62).

Pneumatic Valve Return System (PVRS)

In 1984 Jean-Pierre Boudy and his employer Renault applied for a French patent on a valve return system using gas as the springing medium (474). The conventional valve coil spring was replaced by a piston on the stem in a fixed cylinder containing compressed gas which was compressed further as the valve was opened by a cam in the usual way. Thereby energy was stored in the gas to return the valve to its seat. Renault named this system "Distribution Pneumatique" (DP) but when it was taken up by Honda later they used the description "Pneumatic Valve Return System" (PVRS) which is more precise. Renault put this DP into their 1986 TurboCharged EF15bis 90^0V6 1.5 L and claimed a 14% increase in useable RPM (596).

General adoption of PVRS and its advantages

There was no immediate CoY success for the new Renault EF15bis engine. The company abstained from Grand Prix racing during 1987-1988 but retained DP = PVRS for their entry into the new 3.5 L Naturally-Aspirated formula in 1989. Championship success was slow in coming but, by 1991, it was clear that they had once again pioneered the next major step in racing engine design and it was then generally copied.

The particular advantage of PVRS was given in (468) where Ilmor reported that, in moving to it for their type 2175B 72^0V10 3 L in August 1994, the pressurised gas column had a natural frequency x8 that of a comparable wire coil spring, so putting surge far beyond the operating RPM. As a serendipitous benefit weight – Top-End weight - was reduced. When Brian Hart in 1997 adopted a proprietary Del West PVRS for his 1996-design type 830 V8 3 L, he saved 5kg, about 5% (567).

The need for costly coil valve spring replacement after every event was also abolished.

The gas used in PVRS was usually nitrogen, topped as necessary from an on-board bottle, but the 1999 Ilmor engine had an air compressor to supply the system.

Titanium-alloy Valves: US V8s and Japanese motor-cycles

Far outside the Grand Prix sphere and well ahead of it in time, in 1962 American engine tuners of their large V8 production units with Inlet Valve head Diameter(IVD) up to 2¼ inches, opened by pushrods (PROHV), had reduced their valve gear problems by adopting for the inlets the alloy Ti6Al4V (titanium alloyed with 6% aluminium and 4% vanadium) of only 60% density compared with steel (220). This material was originally a USAF-financed development in the 1950s for jet aero engines and the Californian firm Del West pioneered it for auto racing engines. This material change was often teamed with rifle-drilled hollow valve stems to save more mass.

In 1983 Honda for the 1st time used Ti-alloy valves both for inlets *and exhausts* in their 90^0V4 850cc sports-racing motor-cycles (97). This was satisfactory for a short life. Figures given later for the Yamaha YZF-R7 IL4 750cc for the same racing category showed the practical mass reduction as follows (656):-

	Inlet	Exhaust
(Ti-alloy valves / Normal valves)	0.52	0.56

(The figures imply that the Ti-alloy valve stems were also drilled

Application of Ti-alloy valves to Grand Prix engines

During the TurboCharged era, 1983-1988, it was not possible to cope with exhaust valve temperatures using Ti-alloy and, without having *all* the valves in the lighter material, there could be no gain in MVSP because the heavier exhaust valves would become the valve-bounce-limiter. When the Grand Prix formula reverted to Naturally-Aspirated in 1989 engine designers then adopted all-Ti-alloy valves. The figures for the (non-CoY) Cosworth HB series, as developed, compared to the preceding steel-valve DFR type illustrate the advantages gained (they have to be shown in BNP because internal details are not available):-

	1988	1989	1991
Engine type	DFR	HB2	HB5 (pre-PVRS)(743)
BNP m/s	16	18	20
	Datum	+12%	+25%

Combined PVRS, All-Ti-alloy-valves and DLC

By 1992 the “Dream Design” of “PVRS + All-Ti-alloy-Valves” was well established. Figures 1 and 2 show that, from then onwards, there was a more rapid rise of MVSP versus time than ever before as designers learned to exploit this combination (limited data but over 10 m/s in 2000) and of BNP (28 m/s in 2000) (details from the Ferrari type 049 90^0V10 3 L). In particular the new “Diamond-Like-Carbon” (DLC) very hard, low-friction surface treatment was essential to withstand the contact stresses and rubbing speeds of the valve gear (Note 103).

Post-2000 data

Post this review to the end of 2000 some non-CoY data has been released which seems to show that valve-gear development has reached a peak, as follows:-

Date	Engine	Data Source*	MVSP m/s	BNP m/s
2005	BMW P85**	(1095)	na.	31.5
2006	Cosworth CA/6	(1069) (1092)	na.	31.4

After the regulations imposed Maximum RPM, the BNP figure fell back:-

Date	Engine	Data Source*	MVSP m/s	BNP m/s
2009	Toyota RVX-09H Maximum RPM limited to 18,000.	(1091)	10.0***	28.0

*Some sources additional to Appendix 3:-

(1069) Race Engine Technology No. 20 Jan/Feb 2007 Article by S. Corbyn.

(1091) Race Engine Technology No. 49 Sept/Oct 2010 Article by I. Bamsey.

(1092) Cosworth website 6 October 2010 for CA2010.

(1095) *Ten Years of BMW F1 Engines* M Theissen et al 2010.

**An advanced engine tested but not raced due to a change of life rules. Plotted on Fig. 2.

***IVL given but IOD = 320^0 assumed.

Possible limit to PVRS

It may be that the piston/cylinder sealing materials of PVRS have limited the BNP achievable. Ref. (988) stated that in the 2003 BMW P83 the temperature in the gas reached 250C.

Note 15 Sub-Note A
Wider sample of Bore Speed for pre-WW1 OHV engines

Date	Engine	Data Source	BNP m/s	Type of OHV PR = Push-Rod S = Single D = Double Over-head Camshaft OHC VIA = Valve Included Angle	MPSP m/s
1906	Sizaire	(259)	4.00	PR Inlet + Suction Inlet	7.33
1907	Sizaire	(259)	4.00	Presumed OHV	12.00
1907	FIAT GP	Eg. 2	4.80*	2 Valves/cylinder (2v/c) PR push/pull. VIA = 90^0	8.54*
1908	Sizaire	SO3	4.00	Presumed OHV	20.00
1908	Mercedes GP	Eg. 3	4.13	PROHV Inlet (Side exhaust)	9.60
1910	Lion Peugeot	SO4	2.93**	SOHC Inlet(Side exhaust)	20.53
1910	FIAT S61	(4)	3.58	4 v/c SOHC. VIA = 0	10.45
1911	FIAT S74	(519)	4.00	"	10.67
1912	Peugeot L76	Eg. 4	4.03	4 v/c DOHC. VIA = 60^0	14.67
1913	Peugeot L54	Eg. 5	4.17	"	15.00
1914	Peugeot L45	(485)	4.29	"	15.68
1914	Mercedes M93654	Eg. 6	4.81	4 v/c SOHC. VIA = 60^0	17.05

Average of 10 engines, excluding 1907 FIAT GP* and 1910 Lion Peugeot**
4.1 (+17%; -13%)

Highest/Lowest BNP = 4.81/3.58 = 1.34 MPSP 17.05/7.33 = 2.33

* and ** See next page.

*Suspected to be too high on quoted NP because (4) gives independent ACF test evidence that the original 1905 basic design had BNP = 3.3 m/s. It is unlikely that the cumbersome OHV could have been improved by 45% in 2 years, especially as the power gain was quoted at only 8%. A gain of this amount from RPM would mean BNP = 1.08 x 3.3 = 3.56 m/s.

**Note that Inlet Valve head Diameter/Bore (IVD/B) was 0.77!

Note 15. Sub-Note B

Other DVRS in Grands Prix

1. 1914 French GP: Delage

Designed by Arthur Michelat, the details of the 1914 type S 4 v/c DVRS were concealed by misinformation fed to the press at the time and only revealed in 1986, when a survivor in the USA was dismantled. It included small final-seating springs (597A). It was IL4 4.5 L 94mm/160 = 0.59 (485). The engines were down-for-power in the race after a last minute modification to their valve gear according to (940), which prevented proper seating according to (1047). Only 1 car finished out of 3 in 8th place. Clearly, DVRS had not been mastered and Delage did not use it for their successful post-WW1 2 L and 1.5 L engines.

2. 1960 Scarab

Leo Goossen, *the* American racing-engine designer with a career over 53 years, prepared in 1959 an IL4 2.5 L 3¾ inch/3⅜inch = 1.11 unit for Lance Reventlow's Woolworth-fortune-financed Scarab team. He was told to fit 2 v/c DVRS (1046) copied from a 1955 Mercedes-Benz 300SLR (M196I) given to the Ford museum at Detroit, although the clearance adjustment method differed from the M196. After some initial valve gear trouble (1046) the car, with a front engine inclined at 11^0 to the horizontal (another feature similar to the M196), was entered in five 1960 GPs but qualified only twice because of engine failures or being just too slow. It obtained one 10th place. The 2.5 L formula and the money then both ran out.

The IL4 Scarab and donor IL8 Mercedes DVRS compared as follows (both 2.5 L):-

	1955 M196 GP	1960 Scarab
Data Source	Eg. 33	(943,1046)
MVSP m/s	5.2	4.5
BNP m/s	10.8	11.9

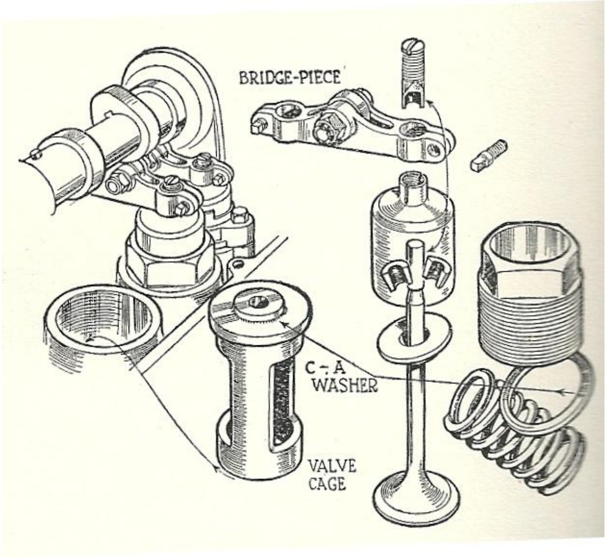
Illustrations

An Appendix gives illustrations of the various types of valve gear.

Appendix

Coil Valve-Spring Return System (CVRS)

There are, of course, many examples of CVRS but an early version applied to OHV for which an illustration is available is the 1911 10.1L FIAT S61shown here.

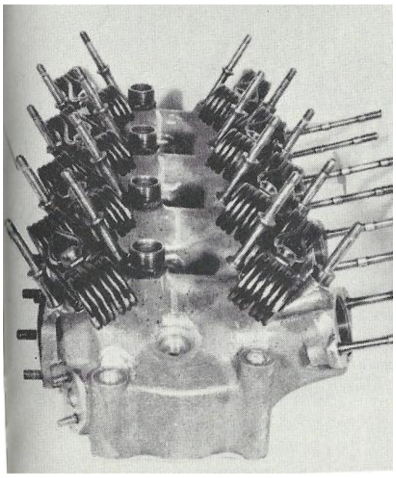


DASO 4

This engine also had possibly the 1st inverted-cup tappets to resist cam side-thrust (see Note 25B).

Hairpin Valve-Spring Return System (HVRS)

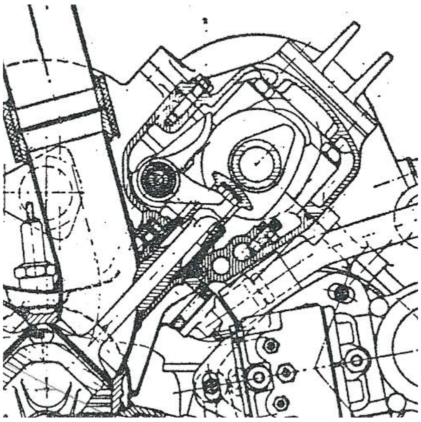
The last CoY engine of only 4 to use HVRS was the 1958 Vanwall V254 shown here (the other 3 were:- the 1949 DOHC 1.5L Ferrari; the 1952 & 1953 2L Ferraris).



DASO 68

Desmodromic Valve return System (DVRS)

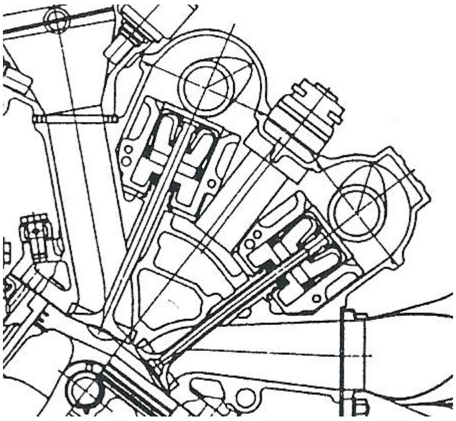
The only CoY engines to use DVRS were the 1954 & 1955 2.5L Mercedes-Benz M196s.



DASO 468

Pneumatic Valve Return System (PVRS)

The illustration is of the 1992 3.5L Honda RA122E/B.



DASO 69