Chapter 9.

Camshafts and Valve Events.

It is obvious that the opening and closing operations of the valves have a profound effect on the performance of any engine and the component that is responsible for this action is the camshaft in virtually all cases. For many years after the emergence of engines with reasonable performance and durability in the 1950s it was almost standard practice to change to a ‘wilder’ cam in pursuit of more, usually because the basic engine would have had a very mild cam. Even manufacturers joined in and this was typified by the BMC Mini of 1959 soon spawning a larger engined sporty version, the Mini Cooper, with cams that opened the valves for 22 degrees more crank rotation, as well as a few other modifications like bigger valves, twin carburetors, and multi-branch exhaust system. The simple pushrod engines of the day could be developed to surprising levels of performance and it was not long before Minis were racing with more than twice the power of the standard product. The same process also took place in the USA where dragsters and Nascar led the way. Even present day top level dragster engines are descended from the iconic Chrysler Hemi which first appeared in 1951.

It was not all plain sailing though, because pushrod valve gear has a lot of mass and flexibility so as engines speeds began to rise camshafts had to be devised that could operate supple pushrods and pliable rockers so that the valves would open and close under some semblance of control.

The Ford Anglia 105E engine was another classic example of the time having a short stroke that invited high revolutions but with valve gear that went into spasms at certain engine speeds. Even the fledgling Cosworth company nearly went backrupt trying to find the answer but at the eleventh hour Keith Duckworth decided to abandon text book theories and devised a cam profile that solved the problem. This opened up the way for development that ended up with these engines screaming to well over 10,000 r.p.m. and dominating the Formula 3 racing era of the late 1960s.

Clearly the design of any cam profile has to be considered as having two distinct aims: firstly, as a means of achieving the most appropriate combination of valve events for the intended functioning of the engine; secondly, as a key part of a mechanism that must control high, but intermittent, forces in order to achieve the first aim.

A valve mechanism for an out and out racing engine required to survive a few hours at up to 20,000 r.p.m. must live near the limit of the stresses it is designed for but most of all it must never reach the point where the loads exceed its tribologic (the interaction between bearing and lubrication qualities) capacity or failure will be instant. A production application with a limit of maybe 8000 r.p.m. does not have to withstand the same level of stress, but will be expected to deliver reasonable refinement, be tolerant of less than perfect maintenance, and last for maybe a minimum of 150,000 miles. The key to success for both is that the mechanism should be designed to keep mechanical stresses within acceptable limits.

The most appropriate starting point will be to consider the valve events but in order to do this a brief foray into the mechanical aspects is unavoidable because of the limitation they place on what is possible, however the more complex mechanical issues will be left for later in the chapter.

The Valve Mechanism.

Virtually all modern four stroke piston engines employ what is known as the poppet valve, which over time has evolved into a reliable, cost effective and efficient device to control the breathing functions of the engine.

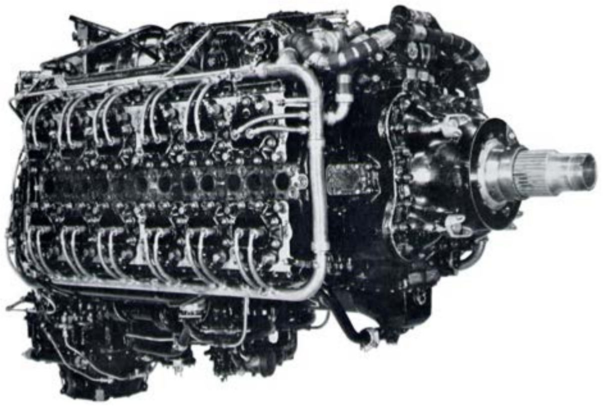

Fig. 9.1 Napier Sabre 24 cylinder sleeve valve aircraft engine.

Of course there are other types of valve that can be used instead of the poppet valve and in the days of big aero engines sleeve valves had a sizable following, strongly influenced by Ricardo's work in this area. The devastating Hawker Typhoon, Tempest and Fury series of fighters were exclusively powered by sleeve valve engines – either the H24 Napier Sabre or the 18 cylinder radial Bristol Centaurus, both capable of producing over 2500 b.h.p. (Fig. 9.1).

But for the emergence of the turbojet it is likely that aero piston engines would have evolved into highly supercharged sleeve valve two stroke units, as advocated by Ricardo and pursued by Rolls-Royce with the amazing V12 Crecy, which sadly never proceeded beyond the prototype stage. Ricardo's single cylinder prototypes had produced over 50 b.h.p./litre /1000 r.p.m., which is in the same realm as the wild turbocharged F1 racing engines of the 1980s. By comparison modern F1 engines (2010) barely scrape towards 20 b.h.p./litre/1000 r.p.m.

Conversely the modern world of two stroke engines is dominated by slide valves (i.e. the piston), rotary valves and reed valves, although there are two strokes with poppet valves as well – more prominently as diesel engines - but none of these are relevant here.

Rotary valves of various types have appeared on four stroke engines throughout its history without ever making much headway against the supposedly inferior poppet valve and there has been a 21st century resurgence for which much has been claimed. However the poppet valve is so deeply entrenched and finely developed that for any challenge to succeed it will have to provide a margin of improvement that seems unlikely to be achievable.

The poppet valve is a fairly simple device to understand and progress with both materials and fuels helped it to become a very reliable means of dealing with the gas exchange process of a piston engine.

In its simplest form a rotating cam pushes on a tappet (cam follower) which in turn pushes on the tip of the valve stem so that the valve opens and closes, springs being provided to maintain the tappet in contact with the cam and to ensure the valve returns to the closed position. The motion is determined by the shape of the cam and can be represented by a 'lift curve' of a more or less harmonic nature (Fig. 9.2).

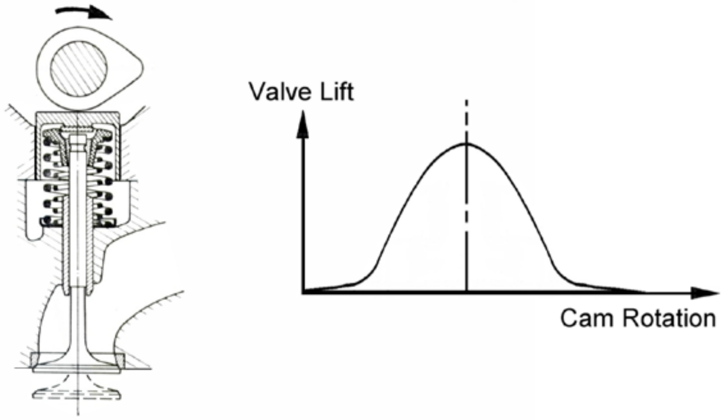

Fig. 9.2 Simple valve mechanism and lift curve.

There are lots of possible variations on the theme with rocking arms and/or pushrods to transfer the motion but the fundamental lift curve is always similar to the example shown. This of course has some influence on the qualities of flow in and out of the engine.

The opinion is sometimes expressed that the ideal mechanism would open each valve instantly to full lift, hold it there, then close it instantly at the completion of the induction or exhaust process. This overlooks the fact that around the top and bottom dead centres piston motion is at its slowest due to the changes of direction, so not much valve lift is actually needed. Also Chapter 6 explained how it is necessary for the descending piston to create a deep suction phase to drive the pulse action that is so important to the induction process, so an inlet valve that opens too quickly may not really be advantageous. It could be argued that there might be some merit in having a rapid opening exhaust valve to create the strongest possible outgoing pulse and lengthen the power stroke but Chapter 7 pointed out that the exhaust valve opening point is relatively unimportant for power output, although thermal efficiency can be improved by later closing.

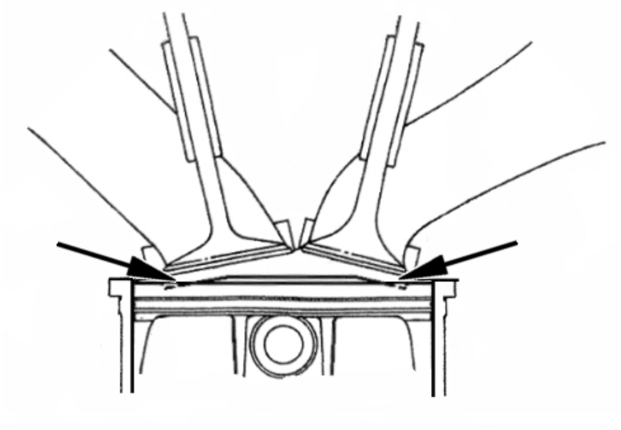

Fig. 9.3 Limited valve/piston clearance typical of F1 race engine.

Around the top dead centre (TDC) position piston clearance becomes a limiting factor with many modern engine designs so the potential for more lift there may be minimal anyway. In fact on very high speed racing engines the piston to valve clearance is a major issue and the quest for earlier valve lift is very much compromised by the need to avoid excessive clearance pockets in the piston crown (Fig. 9.3) in order to maintain combustion efficiency and an adequate compression ratio. During the overlap period the gap between the valve heads and the pistons of such engines may shrink to no more than the tappet clearance of a normal engine, so build accuracy and control of valve motion is extremely critical. The need for such precision is also a reason why those who design such engines rarely risk using variable timing (VVT) mechanisms. There is also some difficulty in producing a VVT system that is able to act fast enough to keep pace with the acceleration capability of a modern racing engine.

With those limitations in mind we can now look into how the valve events determined by the cam affect the gas exchange processes of the engine.

22 pages follow.