Variable Valve Timing and Lift: The Rationale

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It is inherent to the operation of internal combustion engines to possess inlet and exhaust valves (4-stroke) or ports (2-stroke) for proper functioning. The idea here is to entrap the incoming fresh charge in a well-designed combustion chamber and then initiate ignition in order to release and convert the stored fuel chemical energy into the thermal energy. Subsequent to this release of energy, a mechanical system, such as piston-connecting-rod-crankshaft, is needed for conversion of the thermal energy into the mechanical energy of the crankshaft. The incoming fresh charge usually consists of fuel, air, and possibly exhaust gas recalculated (EGR) chemical species. EGR is used for nitric oxide (NO_X) emission control purposes. In this scenario, the roles that valves, particularly the intake valves, play are critical for the engine's efficient operation, optimum performance, and minimization of pollutants emission. In this tutorial, these aspects are addressed in a concise manner.

Historically speaking, many different types of valves and valve actuation mechanisms have been tried in the past. Most have disappeared to the point that at present time nearly all 4-stroke engines use poppet valves opened by a cam and closed by a spring. A typical valve timing for a 4-stroke engine is shown in Fig. 1. At wide open throttle operation of an SI engine, the exhaust gases rushing out of the exhaust valve can assist pulling fresh charge into the cylinder (moving the intake manifold fresh charge even before the piston has moved appreciably), therefore justifying opening of the intake valve (IVO) even before TDC, see Fig. 1. At part load operation, however, situation is a bit more complex and the below-atmospheric pressure created by the partially open throttle valve can become less than the chamber pressure at the time when intake valve is opened. This causes backflow of burned gases from the cylinder into the intake system during the valve overlap period. The overlap period is the time during which both intake and exhaust valves are open (intake is being opened and exhaust being closed). Too early IVO will also cause fresh charge to be lost out of the exhaust, for example, NASCAR engines.

At the closing, it is customary to delay the IVC beyond the BDC to take advantage of the inertia of the fresh charge rushing into the engine, see Fig. 1. This will increase what is referred to as the "volumetric efficiency" of the engine. The volumetric efficiency indicates the breathing ability of the engine and is defined as the actual mass of the fresh air trapped in the cylinder (after valves are closed) divided by the theoretical mass of air calculated based on the piston displacement volume. The higher the volumetric efficiency, the higher the engine ability to trap fresh air, providing opportunity for combustion of a more mass of fuel on account of a more entrapped oxygen, thereby producing higher power for the same piston displacement. Furthermore, the engine brake power rises and then falls off with speed for a number of reasons: mainly the fall in volumetric efficiency, and the fall in mechanical efficiency. The delayed closure of the intake valve for achieving higher volumetric efficiency usually works best at higher engine speeds due to sufficiently high inertia of the incoming fresh charge. Note that the IVO does also affect the volumetric efficiency through the magnitude of the backflow into the intake system mentioned earlier.

In engines, even though attempts are made to thoroughly scavenge the chamber from burned gases, there is always a certain amount of burned gases left to be mixed with the incoming fresh charge. As far as the combustion (really, flame burning rate) is concerned, the amount of this residual burned gases left from the previous cycle combustion is not desirable. The higher the quantity of residual burned gases, the slower the flame mass burning rate. It is known that increases in the valve overlap period will elevate the fraction of the residual gases in the entrapped charge. Also, past research indicates that the amount of the residual gases correlates inversely with the engine load (i.e. throttle valve position in SI engines), being maximum at idle condition. This is the primary reason for engine stability problems at idle condition. It should therefore be clear that the valve overlap period can affect engine stability and hence efficiency. On the positive side, this residual gases is useful to lower the burned gases temperature after combustion is complete, reducing the NO_X emissions. Figure 2 shows effects of the valve overlap period on emissions of NO_X and hydrocarbon (HC) at two different engine loads.

In summary, adjustments in valve timing (usually achieved by camshaft phasing) affect the raw emissions, engine torque/power, and idle stability. However, researchers have shown benefits in tailoring valve lift profile, primarily to achieve higher efficiency and power, although emission benefits were also seen. Combination of adjustments in valve timing and changes in valve lift are being used to influence both emission levels and engine efficiency and, hence, fuel economy. Finally, potential of SI engine load control is being considered through variable lift designs. Research has shown that improvements in fuel economy and emission can be achieved through an optimized combination of variable valve timing and lift, see Fig. 3. To conclude, the adjustment of the valve timing in spark-ignited (SI) engines is dictated by a set of conflicting targets and goals. These goals cannot be achieved with fixed valve timing. Systems that provide variable timing and lift have recently found widespread use in engine design.

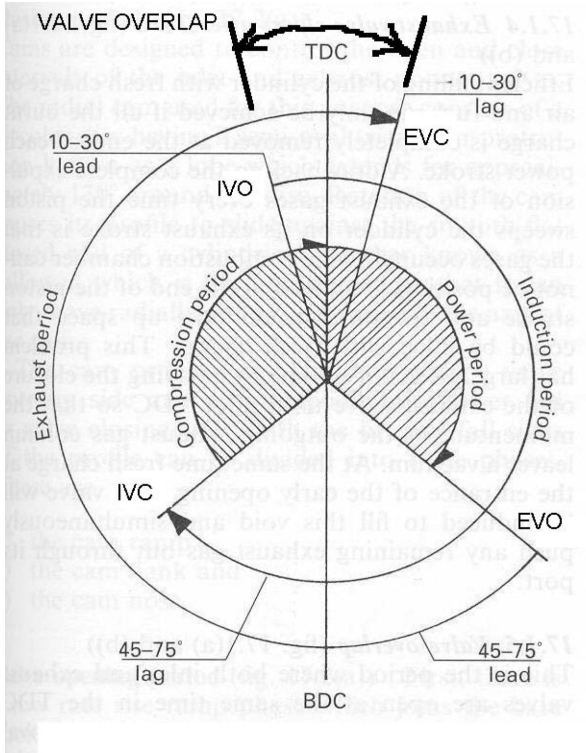

Figure 1. Indicates positions of intake and exhaust valves openings and closures with respect to the top-dead and bottom-dead centers, TDC and BDC respectively. TDC and BDC indicate the uppermost and lowermost positions of the piston top on the diagram. The angles shown are crankshaft angles. EVO and EVC are exhaust valve opening and closures angles.

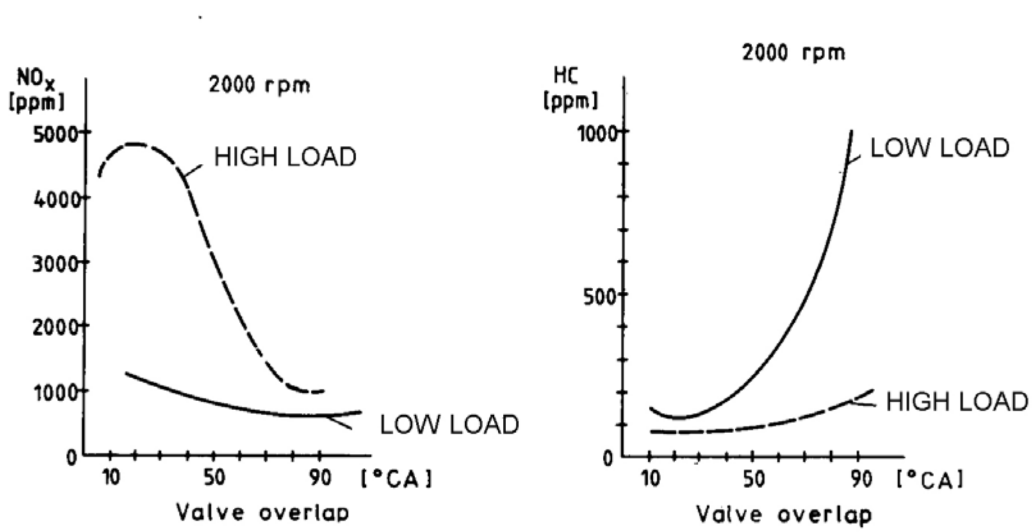

Figure 2. Effects of valve overlap on emission of pollutants at 2000 rpm and two different engine loads. HC and NO_X are hydrocarbon and nitric oxides emissions.

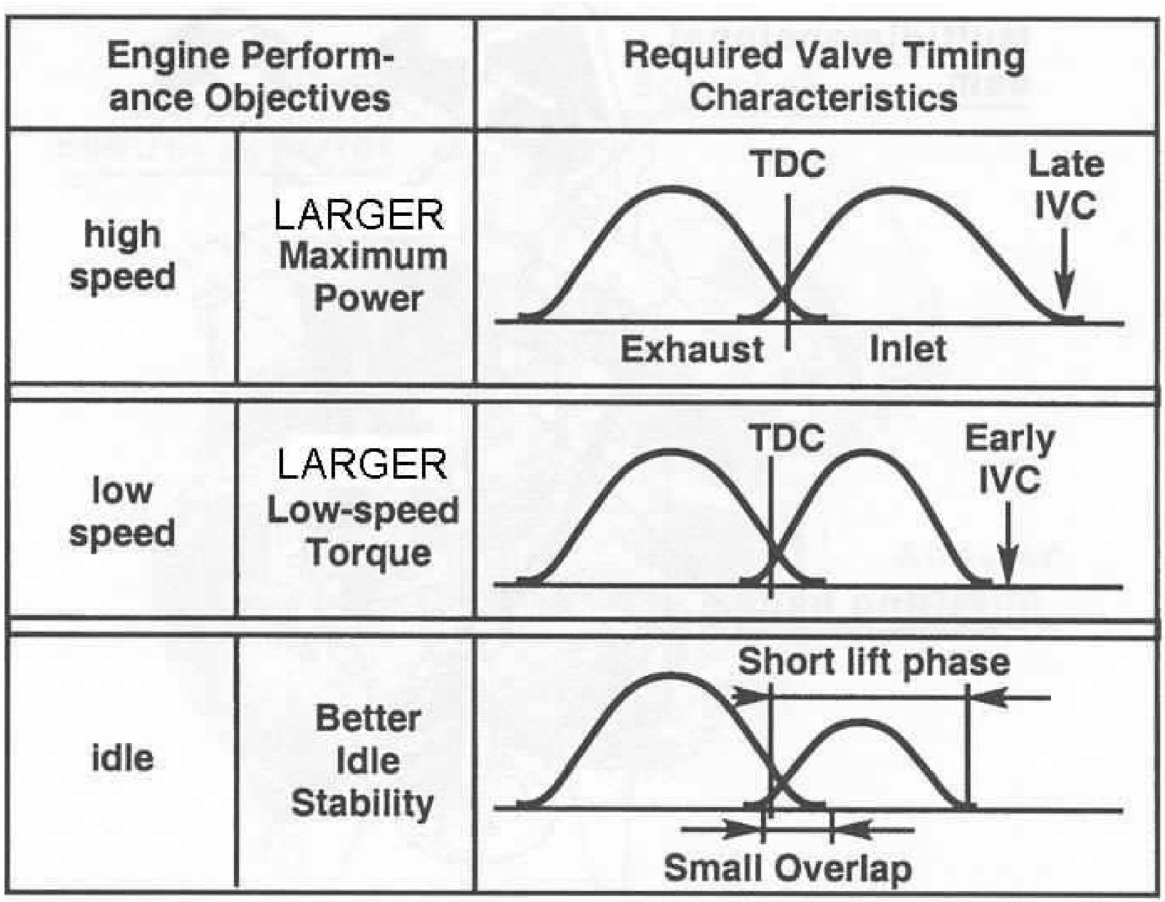

Figure 3. Variable valve timing and lift for Ferrari V8. Vertical axes show the amount of the valve lift. Horizontal axes indicate the carnkangle angular position. The curves show the intake and exhaust valves lift profiles.