Variable Valve Timing for any Engine Concept

Greater power and torque with reduced fuel consumption and lower emissions can be achieved in modern gasoline engines using variable valve timing. The combination of these advantages has previously been obtainable solely with DOHC engines. Only with those type of engines was it possible to modify the valve overlap between exhaust and intake. With the innovative "Cam-In-Cam" camshaft technology, Mahle makes this variability available for any engine concept.

1 Why Variable Valve Timing?

Modern combustion engines must meet increasingly higher requirements. The tightening of legal specifications for pollution emissions, the reduction of fuel consumption with increasing vehicle weight, combined with greater power and torque to improve driving dynamics. In modern gasoline engines, these sometimes incompatible goals can be achieved with variable valve timing for the intake and exhaust valves [1].

The best valve timing of a combustion engine varies at different load and engine speed points. Fixed valve timing is merely a compromise. The variation options generally include single phasing at the intake or exhaust, independent intake and exhaust phasing, and dual equal phasing of intake and exhaust.

Single intake phasing (intake only) is mainly used in engines with small displacement, in order to achieve a good low end torque and maximum performance. The variable closing point of the intake valve can reduce the charge cycle work in the engine's partial load range (Miller-Atkinson process). This provides advantages in fuel consumption. Variable valve overlap also enables control of internal exhaust gas recirculation, in order to exploit additional consumption advantages. Single exhaust phasing (exhaust only) is mainly used to improve emissions behavior (HC, NO_x). Particularly for high-torque engines, intake adjustment can be dropped if the intake timing is set for performance. Also in this case, variable valve overlap can provide consumption advantages. Independent intake and exhaust phasing (dual independent) combines the advantages listed above. This results in maximized values for power and torque, **Figure 1**. With synchronous intake and exhaust phasing (dual equal), about half of the advantages of independent phasing can be achieved. In addition, the valve overlap cannot be changed, which limits idle stability.

2 Applications

Independent phase phasing is currently implemented with two separate camshafts per cylinder head (DOHC engines), **Figure 2**. This design currently provides the greatest degree of freedom for variable valve timing. The cost and increased installation space required, however, are disadvantages.

Since SOHC engines have only one camshaft per cylinder head, the reduced number of parts provides advantages in cost, installation space, and engine internal losses (reduced friction). However, due to its design, only equal phasing of intake and exhaust valves can be realized. The same applies to OHV engines. In these engines, a central camshaft (cam in block) actuates all the valves using pushrods. Especially for American V-type engines, this low-cost and relatively com-

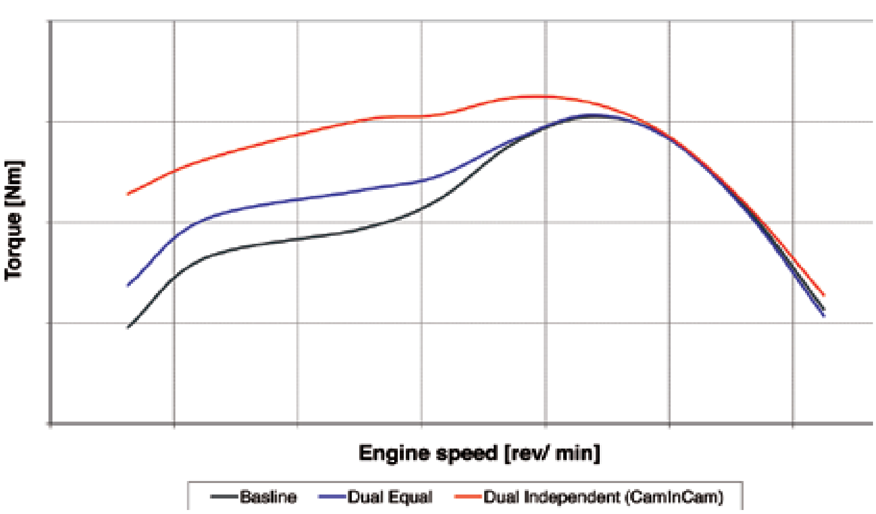

Figure 1: Torque curves for different valve train systems

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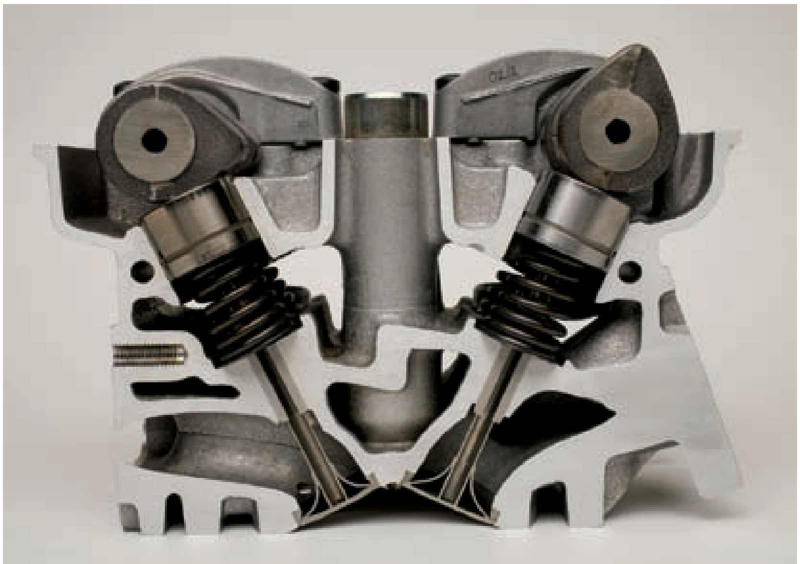

Figure 2: Cylinder head of a DOHC engine with two separate camshafts

pact design is a favorite. The camshaft is located below the valves. A significant disadvantage of these engine concepts, with only one camshaft (SOHC, OHV engines), is their limited variability.

3 Cam-In-Cam Technology

Engines can thus be divided into two groups. On the one hand, low-cost and compact engines with limited variability. On the other, variable but high-cost engines with increased space requirements. In order to resolve these conflicting goals, Mahle has developed the "Cam-In-Cam" technology. Two camshafts in the space of a single camshaft. This enables the integration of a maximum level of variable valve timing in compact and low-cost engine concepts.

Mahle´s Cam-In-Cam technology, **Cover Figure** right, consists of the concentric arrangement of two camshafts in the space of one conventional camshaft. The two camshafts can be phased independent from each other. The cam phaser is mounted on the front end of the inner and outer shaft. Oil supply is provided as in the case of a conventional hydraulic cam phaser, through the front end of the camshaft (e.g., at the first bearing location).

On the outer shaft shown in the Cover Figure center, the fixed lobes are securely mounted to the tube with the circumferential slots. The angular position of the fixed lobes is determined by the outer shaft, as with a conventional camshaft. The inner shaft shown in the Cover Figure left is connected to the adjustable lobes by dowel pins. When assembled, these extend through the slots in the outer shaft. The pins on the cam then transfer the rotary motion to the adjustable lobes, which are radially supported on the outer shaft. The Cover Figure right shows the finished Cam-In-Cam camshaft assembly.

The proven Mahle process allows joining of fully machined components, without plastic deformation. Using this process, Mahle produces millions of composite camshafts annually, with cam contours that do not need to be ground after joining. With the Cam-In-Cam camshaft, small gap dimensions between the moving parts ensure reliable function with regard to valve train dynamics, service life, and lubrication. Further machining on the camshaft would therefore cause problems with contamination, corrosion, and ultimately with the production of correct cam profiles. During assembly of fully machined components, inspection of exact dimensions and controlled joining processes can ensure a high level of quality, and thus of functionality. In the order of assembly, the outer camshaft is first manufactured using the familiar production process. The adjustable lobes are loosely assembled. In additional steps, the inner shaft is inserted into the hollow outer shaft, and the adjustable lobes are aligned to their angular position and pinned to the inner shaft. This solution involving two concentric camshafts, which is now in series, has been known since 1908. Mahle has secured it's serial production solution with patents.

Of course, the effects on valve train dynamics were likewise in the forefront of the development of the Cam-In-Cam camshaft. Bench tests were carried out for a number of engine applications. The valve lift and speed were measured, and conventional camshafts were directly compared to the Cam-In-Cam camshaft. The results showed no degradation of valve train dynamics, **Figure 3**.

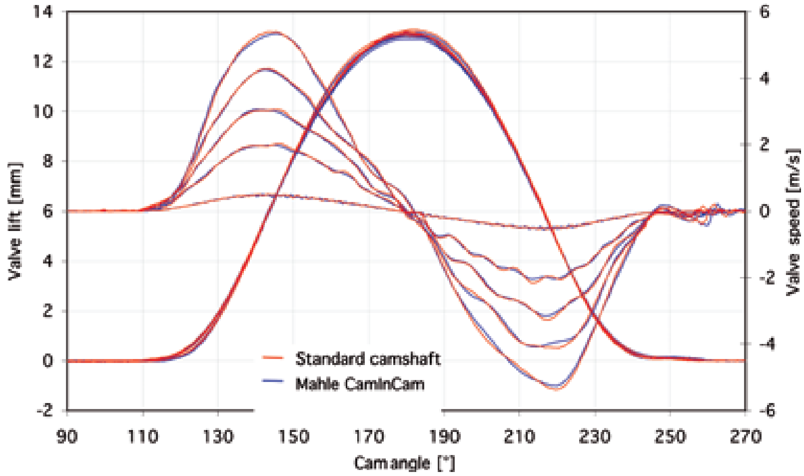

Figure 3: Comparison of valve train dynamics for Cam-In-Cam and conventional camshaft

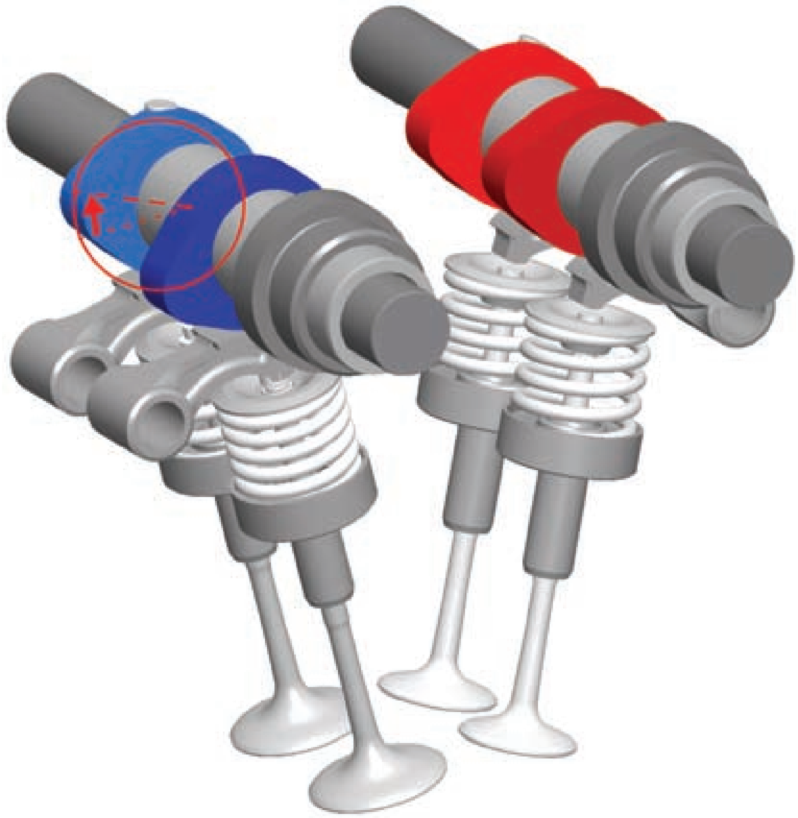

Figure 4: Relative intake adjustment

4 Conclusion

Since the Cam-In-Cam camshaft does not take up any more space than a conventional camshaft, variable timing can be achieved by simply replacing the camshaft. The engine concept and production equipment remain unchanged. Even the oil supply to the cam phaser can be implemented through the camshaft. Adaptations to the engine block and cylinder head are thus kept to a minimum. Hence, the engine manufacturer benefits from the fact that the identical engine layout can be used for different performance and emissions variants. Only the calibration function in the engine control module needs to be adapted for the additional degrees of freedom. Initial applications achieved an increase in performance of up to 20 %, 15 % more torque, Figure 1, fuel consumption reduction of 4.5 %, and 60 % improvement in idle stability [2].

With Mahle´s joining process for camshafts, all components can be fully machined prior to joining, and the moving parts are guaranteed to move freely. The construction of the Cam-In-Cam camshaft ensures that all bearing forces are taken up by the outer shaft, and the inner shaft remains free of bending loads. This makes it possible for the inner lobe to use only the movable lobes as bearings, and prevent seizing. In addition, the contact points between the moving parts are lubricated with oil supply through the camshaft. All of these measures ensure that the adjustment times of typical phase adjustment systems can be achieved.

The weight of a Cam-In-Cam camshaft is generally less than that of two conventional composite camshafts. The low installation space requirement of a SOHC, and especially an OHV configuration, allows freedom in the aerodynamics of the vehicle, or can possibly replace active engine hoods, which are used for improved pedestrian protection.

When Cam-In-Cam camshafts are used in DOHC engines, **Figure 4**, the opening duration can be changed via the relative adjustment of two intake or two exhaust valves. This opens up new possibilities, especially for diesel engines, since they generally do not allow any significant valve overlap. Extended duration of valve opening also opens up new fuel savings potential for supercharged gasoline engines [3].

Cam-In-Cam technology is now in production, and the first customer vehicles of the 2008 Dodge Viper were shipped in December 2007.

References

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