

Variable Intake Cam Duration Technologies for Improved Fuel Economy

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ABSTRACT

Using a 3 liter, 4 valves per cylinder, V6 Diesel engine model, this study investigates late intake valve closing (LIVC) time in an effort to reduce the fuel consumption of the engine. Two different intake cam duration technologies for diesel engines are evaluated using a 1-D engine simulation software code. The first method utilized for duration control delays the effective closing of the intake valve by moving one intake cam lobe with respect to the other baseline intake cam lobe. In the second method, the closing of both intake valves is delayed by the introduction of an adjustable dwell period during the closing portion of the valve motion. During this mid-lift dwell period, the lift is held at a constant value until it goes into the closing phase.

The systems are evaluated and compared at 4 operating points of varying engine speed and load. At each operating point, while engine load is held constant, intake valve closing time is varied. The engine investigated uses a variable turbine geometry (VTG) turbocharger and at each operating point, two operating modes of the VTG are investigated; one with a constant boost pressure and the other with a constant vane position. Besides reporting the fuel consumption benefits of these devices, a full thermodynamic analysis is provided which explains why the devices perform in the manner claimed.

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INTRODUCTION

Although diesel engines remain the fuel economy leaders, the drive for improvements in fuel efficiency remains strong. In particular, as emission regulations on diesels increase, it is a challenge to maintain, let alone reduce fuel consumption. Therefore, many technologies are being examined to improve the emissions and fuel consumption tradeoff. One of the technologies being examined for diesels is variable valve actuation (VVA). This technology has long been applied to gasoline engines as a method of improving performance and fuel economy, but its application to diesel engines is relatively new.

In previous studies in addition to improving fuel economy other possible applications of VVA to diesel engines were investigated, [1][6]. The focus of this paper will be on the late intake valve closing (LIVC) form of VVA, often times referred to as Atkinson cycle operation. There have been several studies [2,3,4,5,6] investigating LIVC as a method of improving emissions of diesel engines. In our own recent studies it was demonstrated that NO_x and Soot could be reduced by using a specific type of LIVC mechanism without an increase in fuel consumption [7][9]. The investigation in this paper focuses on fuel economy implications of LIVC by reduced pumping work and increased efficiency due to the long expansion ratio. Specifically, two different types of ConcentricCam systems enabling LIVC are studied for their effect on engine fuel consumption.

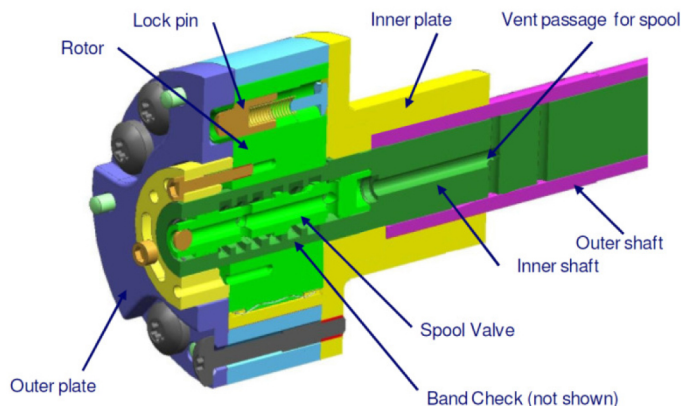


Figure 1. Phaser and concentric camshaft assembly

PHASER AND CONCENTRIC CAMSHAFT TECHNOLOGY

The phaser and concentric camshaft technology investigated in this paper, can be described as a relatively simple (low number of additional moving parts), compact and cost effective solution for changing the valve events. [Figure 1](#) shows the phaser and concentric camshaft assembly.

The basic design principle of phaser and concentric cam technology requires an outer camshaft tube and the addition of an inner shaft mounted concentrically. The camshaft fixed lobes, shown in [Figure 2](#), are rigidly attached to the outer camshaft tube. Rotating cam lobes slide via a lubricated clearance fit over the outer camshaft tube and are pinned to the inner shaft (thru radial slots in the outer tube) which change angular position in relation to the outer camshaft tube. The end of the pins are indicated in [Figure 2](#) by the larger dots. The camshaft phaser rotor is attached to the inner shaft and when the phaser is actuated, it changes the inner shaft angular orientation in relation to the phaser stator which is attached to the outer camshaft tube. The phaser stator consists of the inner and outer plates. If a variation of the timing of the valve event is required in addition, a second phaser or a twin phaser can be applied. The ConcentricCam systems with a single phaser are referred to as Type 1 and Type 2, the systems with two or a twin phaser as Type 3 and Type 4 systems. Type 1 and Type 2 systems will be described in the next two sections and are the focus of the studies presented in this paper. The Type 3 and Type 4 systems were not investigated in this study, but a description is available in [1].

Phaser and Concentric Camshaft - Type 1

[Figure 2](#) shows a partial view of a Type 1 camshaft assembly. By moving the inner against the outer shaft one cam lobe can be phased relative to the other. In two valve engine applications where each cam lobe acts on one valve, intake and exhaust valves can be phased relative to each other. With a special, i.e. rotated, valve arrangement this can also be achieved in four valve engines. In addition, this mechanism can be used in four valve engines to realize LIVC

by phasing one intake valve relative to the other so that the whole valve event is extended. By doing that the integral of the area under the open valves does not increase but is instead spread out over a longer time period. This is the approach investigated in this paper for LIVC with the Type 1 ConcentricCam.

Phaser and Concentric Camshaft - Type 2

The Type 2 ConcentricCam system ([figure 3](#)) is a split lobe design where two cam lobes act on one rocker arm per valve. At one point, one cam lobe “hands off” the task of acting on the common rocker to the other cam lobe. The rocker and therefore the valve follow the maximum of the two cam lift profiles extending the opening duration. In contrast to the Type I system the total flow area under the open valves increases with the Type 2 in the LIVC position. [Figure 4](#) shows how the valve lift profile changes as one cam lobe is rotated with respect to the other cam lobe. It also shows the cam lobe positions at the base position as well as shifted by 60 degrees.

NUMERICAL APPROACH

The commercially available engine simulation code, GT-Power [8], was used for all simulation results reported in this paper. The LIVC mechanisms were studied on a state of the art 3.0L, V6 light duty engine with common rail fuel injection and 4 valves / cylinder. The engine was calibrated for the EPA 2007 US emissions standard. The boosting system utilizes a Variable Turbine Geometry (VTG) turbocharger. A high pressure loop EGR system is also included in the model.

Operating Conditions

[Table 1](#) lists the engine operating conditions that were simulated.

A sweep of the intake valve closing time was investigated for each operating point referenced above. For each sweep the intake valve closing timing was delayed, thus the amount of air inducted dropped. At a certain point, no more fuel could be injected without reducing the air / fuel ratio below the predetermined limit. Beyond this point the load could not

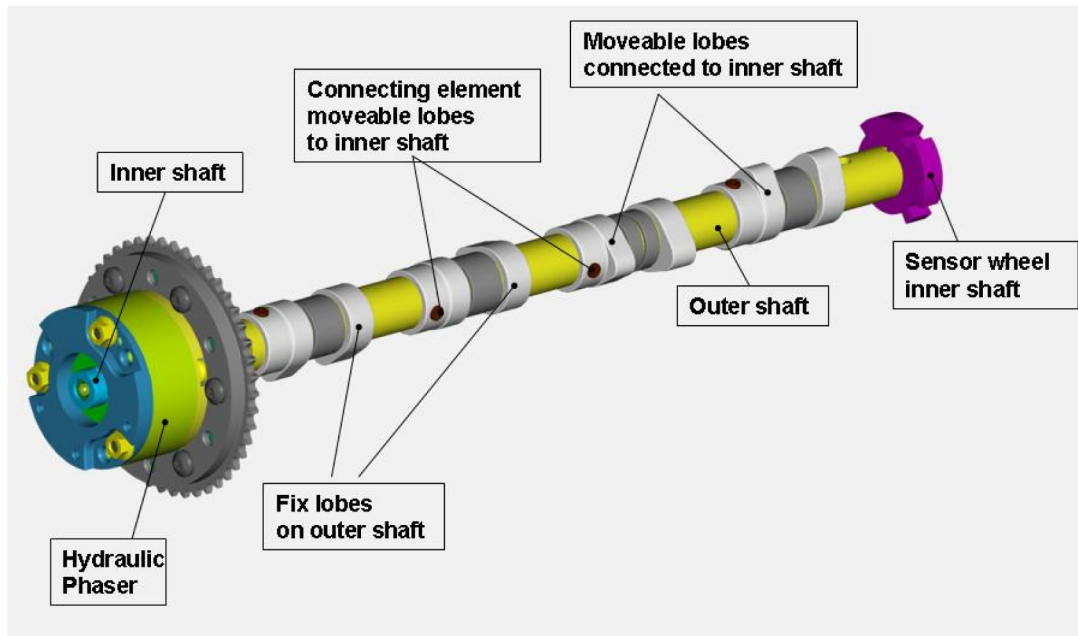


Figure 2. Type 1 phaser and concentric camshaft assembly

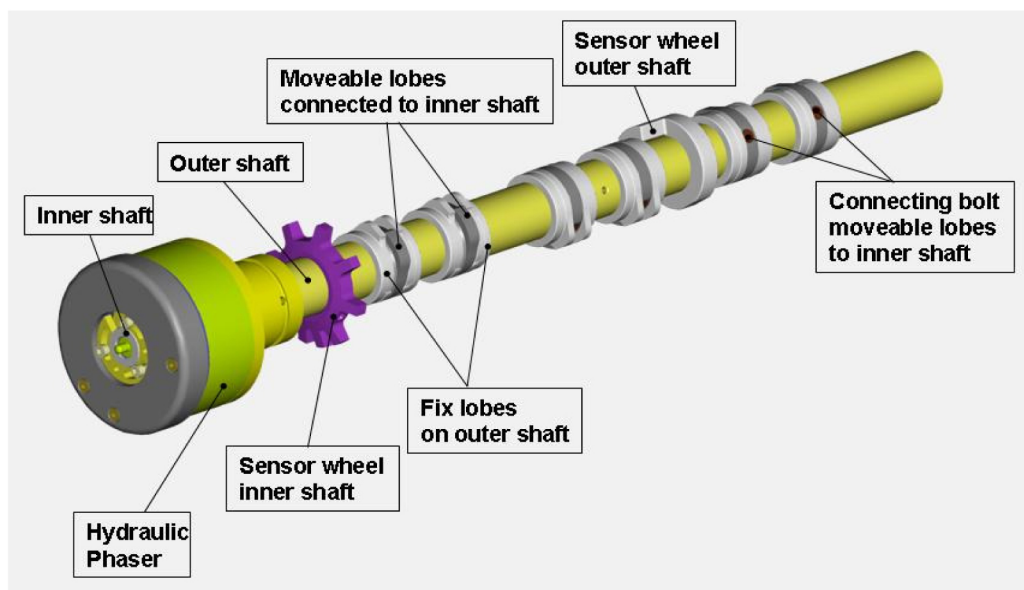


Figure 3. Type II phaser and concentric camshaft assembly with "hand-off" cam lobe.

be maintained so the LIVC limit was reached. Where the limit was not reached the Type 1 intake cam lobe was varied by 60° from its baseline closing time of 26° ABDC to 86° ABDC. Due to the slightly different valve lift profile the base timing of Type 2 is 28° CA ABDC, so for this type the closing time was varied from 28° ABDC to 88° ABDC.

The EGR rate was held constant during the intake valve closing sweeps. Because of the strong relationship between NO_x emissions and EGR rate, one can expect that NO_x will stay relatively constant, or at the very least, the differences

between the NO_x emissions for Type 1 and Type 2 will be small at the same LIVC timings.

Two methods of operation of the VTG were evaluated. In the first, the VTG vane position was held constant. This method minimizes the effect of the boosting system on the results. In the second method the intake boost was held constant by changing the vane position to investigate the effect of the changing turbine backpressure. The interaction of boosting and VDC system becomes evident when the simulation tasks are run with this method.