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Design of . Variable Valve Actuation in I.C.Engine

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ABSTRACT

These major issues are putting pressure on automakers to develop new technologies to increase the fuel economy and decrease the emissions while maintaining or improving the engine's performance. Several new technologies have resulted. All of these technologies accomplish these goals by increasing the efficiency of an engine. As a whole these technologies are called variable valve actuation. These technologies achieve a higher efficiency by reducing the constants of the engine.However, the added variability increases the time to calibrate an engine. To address this, more testing is being performed using engine simulations instead of physical testing. This thesis focuses on how to create an engine model and how engine simulation can be used to optimize such an engine. In addition the benefits of a particular variable valve actuation technology, cam phasing, will be explored

Introduction

A conventional engine has static, mechanically-actuated valves and a compression ratio that is fixed once the components of the engine are chosen. A recently developed technology called variable valve actuation (VVA) enables added control of valve timing, lift and/or duration. With this additional freedom, the efficiency of an engine can be greatly increased. Not only can the compression ratio be increased with the addition of VVA, but also the necessity of throttling can be reduced[1,12]

Although cam phasing has numerous benefits, it also has significant drawbacks. The largest drawback is a substantial increase in the amount of testing required to create an optimized engine map. By using engine modeling, the amount of testing required is reduced because most of the testing is done virtually through a simulation. The creating of an engine model requires a broad range of experimental data. To make an accurate model, the data must span the entire range of operating conditions. However, only a relatively small amount of data is needed. This thesis focuses on how to create an engine model and how to use the model to optimize engine development. In this study the abilities of GT-Power, an engine simulation program, will specifically be explored. Both the cycle resolved and cycle averaged data will be presented. The simulations will show the effect of intake and exhaust cam phasing on the trapped air mass, the trapped residual gases, intake air temperature, indicated mean effective pressure and combustion stability.[2,24]

Variable Valve Actuation

In standard IC engines, the compression ratio (set by the engine's mechanical design) is also fixed for all engine conditions. The compression rate is thus limited by the engine condition with the lowest knock limit. Engine knock is caused by spontaneous combustion of fuel without a spark (auto-ignition).For spontaneous combustion to occur, the temperature and pressure must be sufficiently high. Therefore the limiting condition occurs at wide open throttle (WOT) and engine speeds close to redline. Likewise, lower engine speeds and throttled conditions (the most common operating conditions when driving a vehicle) have much less tendency to knock and can withstand higher compression ratios (hence the potential for higher efficiency).

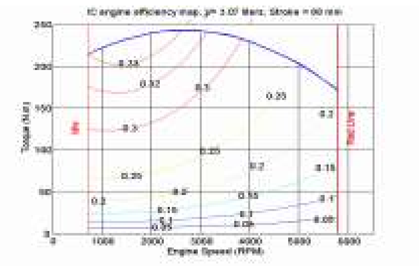

Figure 1: Efficiency Map of a Typical SI Engine (Guezennec, 2003)

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The most common operating conditions for IC engines are low engine speeds and moderately throttled air flow. Unfortunately, the optimum conditions for the average IC engine are at WOT and low to moderate engine speeds. Throttling the intake air creates fluid friction and pumping losses. High engine speeds create greater mechanical friction thus reducing the efficiency. Figure 1 is an efficiency map of an engine with the mostcommon operating region indicated. If the typical operating efficiency of the engine wasimproved, then the fuel economy would greatly increase

The most common use of VVA is load control. A normal engine uses throttling to control the load of the engine. When an engine is throttled, the flow separation created from a throttle body creates fluid losses and the volumetric efficiency decreases. A major goal of a VVA engine is to control the amount of air inducted into the engine without a physical restriction in the flow field. The torque curve of a conventional engine has a very distinct peak that generally occurs in the middle of the engine speed range. The torque produced at low engine speeds is much less because the incoming mixture of fuel and air is at a comparatively low velocity. To increase the torque at low engine speeds, the intake valve should close right after the piston passes the bottom dead center (BDC) between the intake and compression strokes. This will effectively generate a maximum compression ratio for low engine speeds. Increasing the compression ratio at low engine speeds essentially pushes the engine closer to a loaded condition. Conversely at high speeds, the velocity of the intake mixture is large. Thus the optimum condition is where the intake valve stays open longer. The torque curve comparison between conventional and VVA engines is shown in Figure 2.

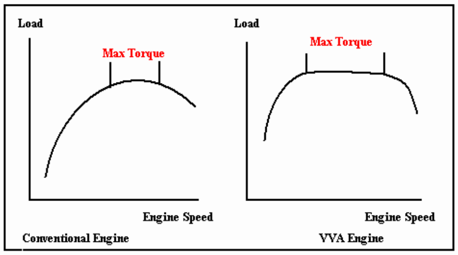
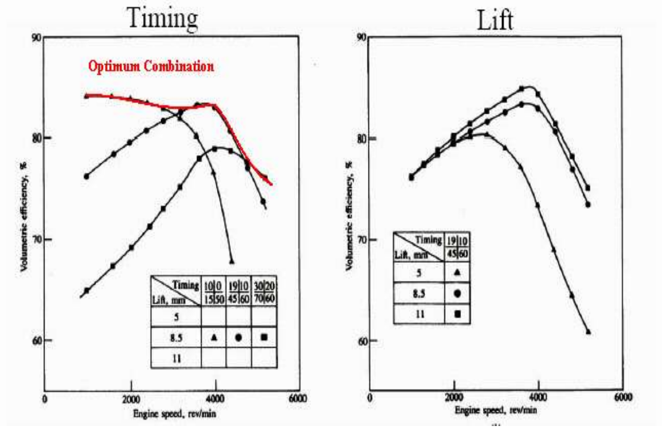


Figure 2: Torque Curve Comparison

Another major use of VVA is internal exhaust gas recirculation (Internal EGR or IEGR). The residual burn fraction is important for all engine conditions. At low engine speeds the percent of EGR should be small, because combustion is already unstable. Moreover, adding combustion products to the intake charge only reduces the combustibility. At higher speeds EGR can actually increase the efficiency and help produce more power. EGR is also important in limiting the emissions of an engine and reducing engine knock[9,18]

Optimum High and Full Load VVA Techniques

At full load the efficient induction of air is the most important factor. Therefore, the intake cam should have a very steep and long profile. The profile should be as aggressive as possible within the knock limit. The valve overlap should be moderate to high to increase the residual gas fraction. The intake valves should be closed well after BDC to increase the volumetric efficiency. Figure 11 shows a graph of volumetric efficiency versus engine speed for three different valve timings. It also shows the volumetric efficiency versus valve lift. As the valve lift is increased, the volumetric efficiency increases. The maximum efficiency occurs when the valve lift creates an opening area equal to the port area.[12,20]



Optimum Timing and Lift Chart (Heywood, 1988)

Experimental Methodology

All testing was performed at The Ohio State University's Center for Automotive Research in an engine dynamometer test cell. The testing was performed on a modern.2 liter four cylinder gasoline preproduction engine. The fuel is port injected and spark ignited. Both the intake and exhaust cam timing can be controlled independently with a15 CAM degree range. A picture of the engine is shown in Figure 13. Because it was a preproduction engine, its prototype calibration varied slightly from the production one. In addition several physical modifications were made to the engine. The radiator and cooling system were removed and replaced with a liquid water heating system. To provide a consistent source of air, the intake system was attached to a 50 gallon drum that draws room temperature air.

Picture of the Engine Experimental Setup

In addition to these modifications, many other components were instrumented so that data could be collected. A laminar flow sensor was attached to the entrance of the intake manifold to measure the mass flow rate of the air entering the intake. Two pressure sensors were placed in the intake system. One measures the ambient pressure and the other measures the manifold air pressure. The intake system was also outfitted with several thermal couples to provide a temperature distribution for the intake. Each runner in the intake manifold had two thermal couples to measure the wall temperature and air charge temperature. Another set of thermocouples was placed to measure the pre- and post-throttle temperatures. The exhaust system was also outfitted with several thermocouples. Another important modification to the exhaust is the addition of multiple heated exhaust gas oxygen sensors (HEGO) and universal exhaust gas oxygen sensors

Experimental Procedure

As previously stated, the goal of the testing was to determine the impact of intake cam timing, exhaust cam timing, engine speed and manifold air pressure on combustion. Because time is a major constraint, the testing points were chosen in a semi-random manner such that the whole range of engine conditions was covered with a relatively low number of points. The data set collected is sparse in the four dimensional parameter space yet it is space filling. Each operation point, which consisted of distinct values for the four parameters discussed earlier, was allowed to reach steady state after which thirty seconds of data was taken. The data was then averaged for each of the operating points. For the in-cylinder pressure data, 200 cycles of data was collected and the data was averaged for each crank angle degree.

A total of 422 operating points were chosen to best represent the most encountered engine conditions. The engine speed ranged from 1000 to 3500 rpm and the manifold air pressure ranged from 0.2 to 1 bar. Both the intake and the exhaust cams had a range of 0 to 50 crank angle degrees. The step sizes for the operating conditions were
200 rpm, 4 crank angle degrees and 2 degrees of throttle angle. Because the manifold air pressure was controlled with the throttle angle, the manifold air pressure was not limited to a discrete set of values.

Combustion Modeling

The most common method of defining combustion is with a mass fraction burned curve. Mass fraction burned is the ratio of the cumulative heat release to the total heat release as shown in Equation 5.

$$MFB(\theta) = \frac{\int_0^{\theta} \frac{dQ}{d\theta}}{Q}$$

Equation 5: Mass Fraction Burned Equation

The mass fraction burned is also defined as the ratio of the apparent heat release to the lower heating value as shown in Equation 6. Therefore if the mass fraction burned is known as a function of crank angle, then the apparent heat release can be approximated In this equation, θ is crank angle degrees with θ_0 corresponding to the initialization of heat release and $\Delta\theta$ corresponding to the duration of burn. The equation is also defined by two constants *a* and *m* which have typical values of 5 and 3 respectively. Because the expression is one minus the inverse of an exponential term, the mass fraction burned is limited to values between zero and one as expected. A sample Wiebe curve is plotted in Figure 19.

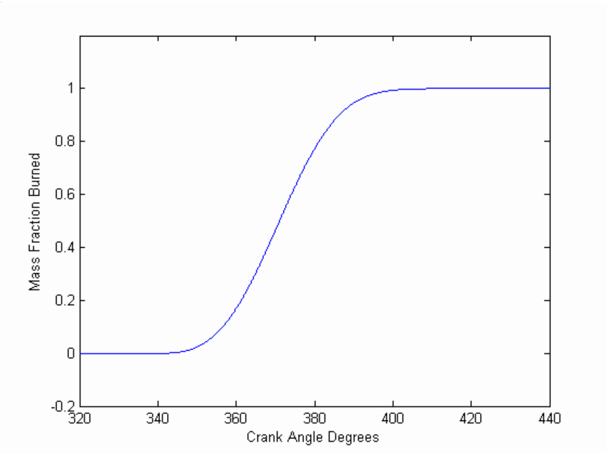


Fig: Representative Wiebe Curve

Future Research

The experimental data used to generate the model was taken on an engine dynamometer. In industry a standard cycle of testing is usually performed. Once the physical design of an engine is performed, engine dynamometer testing is usually performed. At this stage in development, the final vehicle design is not complete and a prototype vehicle is not usually available. In addition an engine test cell is much smaller and easier to run than a chassis dynamometer or in-vehicle testing. Therefore, engine dynamometer testing is initially performed to gain preliminary data. Steady-state data is more easily dealt with than transient data.An engine dynamometer is proficient at maintaining constant conditions.[5,15]

Conclusions:

Choosing a cam pair requires a compromise between several parameters. These parameters include the torque output (IMEP), the trapped air mass, the residual air mass, the volumetric efficiencies and fuel efficiency. The optimum cam position also depends on several external conditions. Depending on the target condition, each parameter's importance shifts. During heavy accelerations maximizing torque output is the main goal. During heavy deceleration fuel efficiency is the most important. Often times the fuel ratio is leaned to further reduce the fuel consumed.There are several other conditions where the optimum cam pairs must be a compromise of several parameters. All load conditions between hard acceleration and hard deceleration will have a different optimum cam pair. For some conditions reducing emissions is the most important. In these situations the trapped residual gases would be increased by increasing the valve overlap. Other conditions have fuel efficiency or torque output as the paramount factors. For most cases the cam pair with the highest volumetric efficiency that satisfies the residual requirement and meets the torque demand would be chosen

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