Camshafts: What’s All the Fuss About?

Basic Principles and Performance:
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The camshaft is arguably the most complex component in an internal combustion engine\(^1\) and very few people know how they actually work. The function of the camshaft is to control the valve timing, ensuring that the valves open and close at the proper time to allow fuel and air to enter and exit the engine. The size, shape, and placement of all the eccentric bumps on the camshaft make the engine operate properly. Despite the complexity, camshaft terminology can be easily understood when absorbed in small pieces. This description will explain the basic principles of camshafts and the effects they have on overall engine performance.

**History**

Camshafts have been used in internal combustion engines since 1876 when Nikolaus Otto invented the first successful four-stroke engine. This engine, although crude, is historically significant and was adopted as the standard design for future motored vehicles (“The History of the Automobile”). Today there are over 100 million cars on the road, all of which employ a camshaft to produce the power necessary for motion (“Commuting to Work”). The placement of the camshaft within the engine has changed numerous times throughout history. In recent memory, the pushrod and the overhead camshaft are the most common design types. Figure 1 shows a pushrod engine where the camshaft resides below and to the side of the combustion chamber. In this arrangement the camshaft moves lifters, which move pushrods, which rotate rocker arms, and finally open the proper valve as shown in the figure. Comparably, Figure 2 shows a single overhead camshaft design in which the camshaft is oriented directly above the combustion chamber, and directly moves the valves. Both camshafts are driven by the crankshaft with a timing chain (or in some cases a belt) and a series of gears. For the purposes of this discussion, pushrod engine characteristics will be reviewed, but these basics apply to any four-stroke engine, from a lawn mower to a racecar.

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1. internal combustion engine: an engine where the combustion of fuel takes place within the engine. Most common engine used today.
The most basic aspect of a camshaft is lift. The shape of a typical camshaft lobe is shown in Figure 3. If you start with a circle and add a bump to a portion of that circle, you have created an eccentric. This is how the rotational motion of the camshaft changes into linear (up and down) movement to operate the valves. Lift is defined as the difference in height between the radius of the base circle and the height of the eccentric as shown in Figure 3. In this figure, the value is 0.350-inch, which is defined as lobe lift. In a pushrod engine that consists of a rocker arm assembly, the rocker arm acts as a leverage arm, multiplying the lobe lift by a determined ratio. Referring back to Figure 1 will give you a visual of what a normal rocker arm looks like. Typical rocker arm ratios are between 1.5:1 and 1.7:1. For example, a lobe lift of 0.350-inch with a 1.5:1 rocker arm ratio would produce a maximum valve lift of 0.525-inch (0.350 X 1.5 = 0.525).

Camshaft lift directly affects the power output of an engine. By increasing lift and opening the valves further, more flow area is provided to allow fuel and air to enter and exit the engine. All engines benefit from increased lift, but there are limitations to individual engine designs. Common factors limiting maximum lift are valve spring capabilities, rocker arm clearance, clearance between the valves and the pistons and durability issues. Increased lobe lift will increase the power output of an engine, but other camshaft characteristics also have an important effect on the power potential.

**Duration**

The amount of time (in degrees) that camshaft lift is generated is called the duration of the lobe. The camshaft lobe in Figure 4 has a duration of 141 degrees. Duration is simply the amount of time the camshaft is not on the base circle, but instead on the eccentric creating lift. All camshafts operate at half engine speed (half crankshaft speed), meaning that for one revolution of the camshaft, the crankshaft will have revolved two times. This relationship causes the duration seen in Figure 3 to be doubled, resulting in 282 degrees of actual duration for this particle camshaft lobe.

Duration has a great effect on engine performance characteristics. A relatively small amount of duration will provide a smooth, crisp idle and excellent part-throttle operation. If the duration is

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increased, the intake valve is open for a longer period of time during the induction cycle\(^2\). Added duration tends to reduce low-speed throttle response and power, but increases power at higher engine speeds. Huge amounts of duration cannot be obtained because duration is inversely proportional to engine vacuum. Engine vacuum is a measure of the amount of airflow restriction through an engine, and is vital to run accessories such as power brakes and cruise control. The ideal amount of duration depends a lot on the purpose of the engine. Performance applications will have relatively large amounts of duration, while towing vehicles will have small amounts.

**Centerlines**

Centerline is the term used to determine the placement of the lobes both on the camshaft and in the engine. Each lobe of the camshaft has a centerline (or midpoint in its duration curve) as shown in Figure 4. This example shows an intake centerline of 106 degrees and an exhaust centerline of 118 degrees. Centerlines are important because they establish exactly where the camshaft is phased in relation to the rest of the engine to ensure proper valve timing.

**Lobe Separation Angle (LSA) and Overlap**

Lobe separation angle (commonly referred to as LSA) is the dimension that specifies the distance or spread between the intake and exhaust centerlines. Calculating LSA is a simple procedure when lobe centerlines are known. For example, the profile in Figure 4 has an intake centerline of 106 degrees and an exhaust centerline of 118 degrees. Add the two centerline values and divide by 2 to get the lobe separation angle \([(106 + 118) / 2 = 112\text{ degrees LSA}]\). Lobe Separation Angle is very important because it establishes the amount of overlap between the intake and exhaust. Overlap is the amount of time (in degrees) that both the intake and exhaust valves are open in the cylinder. Figure 6 on the next page shows two different camshaft profiles with the same 112 degree LSA, but varying amounts of overlap. Camshaft B has more duration than Camshaft A, causing an additional overlap, 43.5 degrees versus 14 degrees, in order to maintain the same LSA. The figure makes this easy to understand. The larger or fatter lobes of B represent the higher duration and it is easily seen how this will increase the overlap.

The correlation between camshaft centerlines, lobe separation angle, and overlap are a very important and difficult concept to understand. As the spread between the lobes tightens, the lobe separation gets smaller and overlap increases. A larger LSA means less overlap because the lobe centerlines are moving farther apart. This gets tricky because if you increase duration, this automatically increases the overlap

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\(^2\) induction cycle: the cycle in a four-stroke engine that draws fuel and air into the combustion chamber.
with the same LSA. Big camshafts (high lift and duration) have wider lobe separation angles in an attempt to limit the amount of actual overlap between the two lobes.

Lobe separation angle and overlap have great affects on engine performance and characteristics. Increasing the amount of overlap, or a small amount of LSA, raises the power curve to a higher rpm, while hurting power at low engine speeds. Large amounts of (but not excessive) overlap is a prime key to large power output, but engine application will determine how much overlap can be tolerated. Figure 6 is a good estimator of the amount of overlap that is used in different situations. An all out racecar, for example, can handle 85-100 degrees of overlap, while a regular street engine should be between 30-60 degrees. This figure will help to define what overlap is expected in various vehicles.

**Conclusion**

There’s much more to camshafts than this short description can deliver, but these basic concepts and terms will give you a much better understanding. The overall function of a camshaft is to control the valve timing in an internal combustion engine, and millions of vehicles throughout the world rely on camshafts to fulfill this function. *Popular Hot Rodding* has an excellent article in their June ’07 magazine, called ‘Be the Camshaft Expert,’ which goes more in-depth on camshaft attributes and performance characteristics. Although a complex and vital component in an engine, camshaft function can be easily understood when broken down into individual segments.

**Figure 6:** Overlap is the amount of time (in degrees) that both the intake and exhaust valves are open. Camshaft B has more duration than Camshaft A, causing an additional overlap, 43.5 degrees versus 14 degrees, in order to maintain the same LSA.

**Figure 7:** Different amounts of overlap are designed into camshafts depending on the use of the engine. Large amounts of overlap are found in racecars.
Works Cited

Visuels:


Information:
