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Material Optimization of a Four-wheeler Cam Shaft

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Abstract:

The cam shaft and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. It consists of a cylindrical rod running over the length of the cylinder bank with a number of oblong lobes protruding from it, one for each valve.

The cam projections make the valves open by pushing on the valve, or on some moderate component as they turn. This analysis is an important step for fixing an optimum size of a camshaft and knowing the dynamic behaviors of the camshaft. Initially the model is created by the basic needs of an engine with the available background data such as power to be transmitted, forces acting over the camshaft by means of valve train while running at maximum speed. In this work, a camshaft is designed for multi cylinder engine and 3D-model of the camshaft is created using modeling software pro/Engineer. The model created in pro/E is imported in to ANSYS.

Key words: ***Design; Evaluation; Cam Shaft; Multi Cylinder Engine.***

INTRODUCTION

A car camshaft is a rotating cylindrical shaft used to regulate the injection of vaporized fuel in an internal combustion engine. These are occasionally confused with the crankshaft of the engine, where the reciprocating motion of the pistons is converted into rotational energy. Instead, camshafts are responsible for the accurately-timed fuel injections required by internal combustion engines [1]. Camshafts have multiple cams on them, which are used to open valves through either direct contact or pushrods. A camshaft is directly coupled to the crankshaft, so that the valve openings are timed accordingly. For better understanding what camshaft is learn how it works. Let's take a closer look.

An early cam was built into Hellenistic water-driven automata from the 3rd century BC. The camshaft was later described in Iraq (Mesopotamia) by Al-Jazari in 1206. He employed it as part of his automata, water-raising machines, and water clocks such as the castle clock. The cam and camshaft later appeared in European mechanisms from at least the 14th century, or possibly earlier.

The key parts of any car camshaft are the lobes. As the camshaft spins, the lobes open and close the intake and exhaust valves in time with the motion of the piston. It turns out that there is a direct relationship between the shape of the cam lobes and the way the engine performs in different speed ranges [2-3].

When the intake valve opens and the piston starts its intake stroke, the air/fuel mixture in the intake runner starts to accelerate into the cylinder. By the time the piston reaches the bottom of its intake stroke, the air/fuel is moving at a pretty high speed. If we were to slam the intake valve shut, all of that air/fuel would come to a stop and not enter the cylinder. So how does a camshaft work in terms of engine performance? By leaving the intake valve open a little longer, the momentum of the fast-moving air/fuel continues to force air/fuel into the cylinder as the piston starts its compression stroke. So the faster the engine goes, the faster the air/fuel moves, and the longer we want the intake valve to stay open. We also want the valve to open wider at higher speeds -- this parameter, called valve lift, is governed by the cam lobe profile [4]. The way camshafts work may impact on an engine's performance at different speeds.

PERFORMANCE CAMSHAFT

The two important aspects of a camshaft, in terms of engine performance, are camshaft duration, or cam duration, and valve lift. Both cam duration and valve lift are determined by the camshaft lobe.

Cam duration is the time that at least one valve of a cylinder remains open, i.e., off its valve seat, measured in degrees rotation of the crankshaft, while valve lift is the maximum distance the valve head travels from Valve lift is somewhat related to intake valve head diameter:

- An engine with an intake valve head diameter of 1.400in to 1.500in will generally perform best with a valve lift of 0.395in to 0.475in;
- An engine with a larger intake valve head diameter of 1.750in to 1.875in will generally perform best with a valve lift of 0.425in to 0.550in;
- An engine with a large intake valve head diameter of 2.000in to 2.250in will generally perform best with a valve lift of 0.475in to 0.650in.

But these are just rough guidelines; ultimately you will need to take some gas flow readings on a flow bench to determine the best valve lift for your particular engine [5].

A number of factors influence valve lift. The most important being the gap between the intake and exhaust valves, the piston to valve clearance and the intake charge pressure. These factors also influence cam duration. Another factor influencing valve lift is valve spring compression.

Obviously, once the valve springs are fully compressed, it cannot give any more and the valve cannot be pushed further down into the combustion chamber. As I've mentioned earlier, cam duration is measured in degrees rotation of the crankshaft, rather than the camshaft, and the crankshaft completes two full rotations for every rotation of the camshaft. In other words, with a 310 degree camshaft, the valves are open for only 155 degrees of actual camshaft rotation.

Fig 1: Cam Shaft

A performance camshaft for a naturally aspirated engine will have duration in the range of 270 degrees to 310 degrees or more:

- 270 degree camshaft described as a 'mild' camshaft
- 310 or more degree camshaft being described as a 'wild' race camshaft

A stock camshaft usually has duration of around 270 degrees but what differentiates a 270 degree performance camshafts from a stock camshafts is increased valve lift and a much faster rate of valve lift. With a faster valve lift rate, the valve reaches full lift quicker and remains at full lift for longer.

SELECTION OF CAM SHAFT

A determining factor, when choosing camshaft duration is the purpose of the vehicle. The longer the duration of the camshaft, the further up the rev range the power band shifts, and the rougher the idle.

Obviously, as the power band moves higher up the rev range, bottom end power is lost. Also, as cam duration and valve overlap increases, torque is lost. Fuel efficiency also decreases and exhaust emissions increase as valve overlap increases.

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High performance camshafts start at 280 degrees of duration. These performance auto accessories have increased valve overlap but not too much so emissions and fuel economy are not severely affected [6]. These are generally good engine camshafts for modified street cars and produce good power from 2,500 RPM up to 7,000 RPM but they do not have a smooth idle because of the increased valve overlap.

A 290 degree aftermarket camshaft requires more cylinder head work in terms of cylinder head porting and gas flowing as they work better when the engine's Volumetric Efficiency (VE) is improved. As you'd expect, these camshafts produce a fairly rough idle. These camshafts are generally good for rally cars and produce power from 3,000 RPM up to 7,500 RPM.

300 degree performance cams require even higher levels of VE, reaching the physical gas flowing limitations of a two valve cylinder head with a single camshaft. These camshafts are good for modified race cars and produce good power from 4,000 RPM up to 8,000 RPM. However, they have a very rough idle.

Performance cams with duration of more than 300 degrees are race camshafts with a power band in the 4,500 RPM to 9,000 RPM rev range. To make effective use of a 300 degree camshaft, you need to ensure that the engine has a very high VE. You also need to ensure that the engine can rev beyond the red line of most stock engines.

CAM

Angle and Lift:

There are several terms and abbreviations which are used when discussing camshafts. The following abbreviations have to do with the location of the piston in the cycle.

TC or TDC, Top Center or Top Dead Center (piston at the highest point) BC or BDC, Bottom Center (piston at lowest point)

BTC or BTDC, Before Top Center (piston rising) ATC or ATDC, After Top Center (piston lowering) BBC or BBDC, Before Bottom Center (piston lowering) ABC or ABDC, After Bottom Center (piston rising)

Some of the other terms used are illustrated in the drawing and are explained below

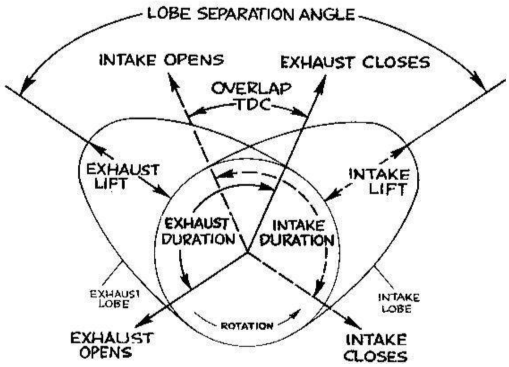

Fig 2: CAM Schematic

Valve opening and closing angles, the angles when the valves first leave and then return to their seats, the opening and closing angles may also refer to a specified nominal lift, e.g. at 0.050 in cam lift. For example, a cam’s timing may be stated as 25-65-65-25. These numbers are (1) in-take opening BTDC, (2) intake closing ABDC, (3) exhaust opening BBDC and (4) exhaust closing ATDC. For these numbers to have meaning, the lift at which the numbers are taken must be specified.

Lobe

Some of the terminology, which describes a single lobe, is illustrated in the drawing below.

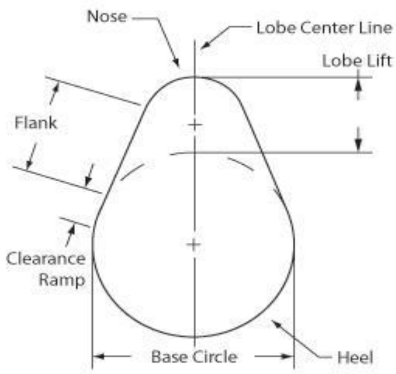

Fig 3: Lobe

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Heel or Base Circle, the portion of the cam which is concentric with the bearings and has no lift. Ramps, immediately adjacent to the base circle, the cam has a portion with low velocity so there is not a major collision as slack is removed from the valve train at the start of the lift event. Similarly, a closing ramp is used so the valve will seat gently and not bounce off the seat. Flanks, the portion of the cam with large acceleration and velocity to get the valve moving as quickly as possible Nose or Toe, the portion of the cam with the smallest radius of curvature, opposite the heel. This part has the greatest lift. Asymmetric Lobe, the opening and closing side of the cam are different.

MODELING AND ANALYSIS OF CAM SHAFT

CAM Shaft in Part Design Model

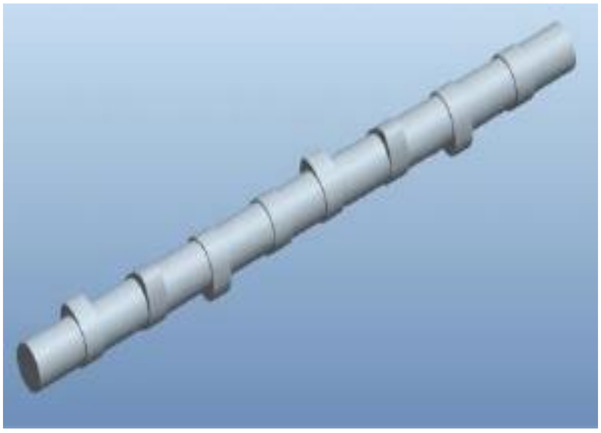

Fig 4: Model of CAM Shaft Analysis of CAM Shaft with Different Materials

Analysis with Cast Iron

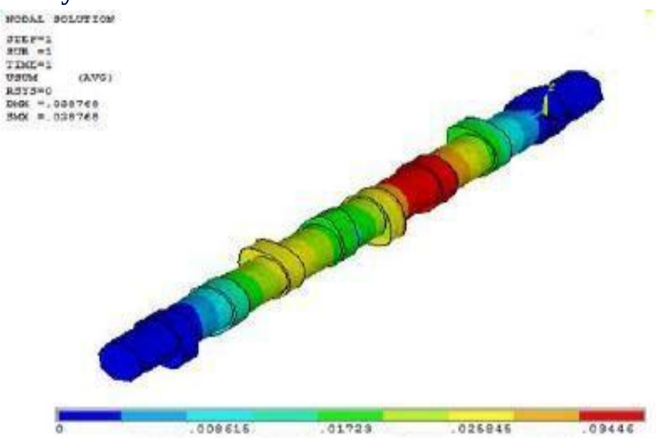

Fig 5: Displacement of cam Shaft

Analysis with Aluminum Alloy A360

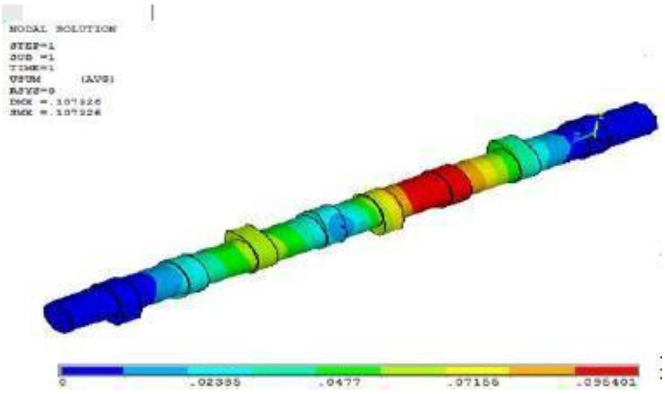

Fig 6: Displacement of cam Shaft

Analysis with Forged Steel

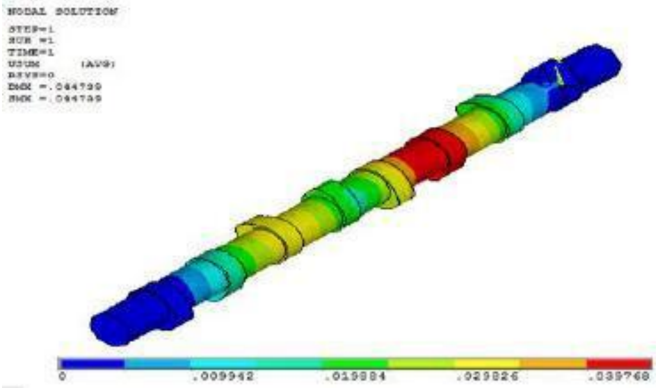

Fig 6: Displacement of cam Shaft

Modal analysis of existing camshaft is carried out. As per analytical solution deflection of camshaft was $5.985*10^{-4}$ mm. from analysis result max deflection is $0.48*10^{-3}$mm. Maximum bending stress in camshaft is 12.656MPa from analytical solution and from 11.094MPa. Comparing analytical and analysis results it is clear that designing of camshaft is correct and safe.

CONCLUSION

Analysis was carried out to evaluate the design using traditional materials cast iron and forged steel. Material optimization was carried out to replace the traditional material with new composite alloys. The values of natural frequency should match with traditional camshaft. After model analysis dynamic frequency analysis was done to determine the displacements due to external vibrations. According to the results obtained from the analysis aluminum 360 (special grade for casting automotive parts) is the best choice for camshaft manufacturing.

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