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Design and Analysis of Camshaft & Development of CAM Code for Die Manufacturing

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ABSTRACT: The camshaft 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. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears. Cams are made as integral parts of the camshaft and are designed in such a way to open the valves at the correct timing and to keep them open for the necessary duration In this paper a cam shaft is designed for PS 24/2 stationary multi cylinder engine by using theoretical calculations. Based on theoretical calculations, a 3D model of the camshaft is created using Unigraphics software. Static structural analysis is done using ANSYS with two different materials such as structural steel and aluminum alloy 7475 (AL 7475) to determine displacements and stresses developed in the camshaft. Core & Cavity is extracted for the cam shaft and CNC program is generated for both core and cavity using NX design software.

Key words: Design, Analysis, CAM, Die manufacturing, CNC

I. INTRODUCTION

A cam is a rotating or sliding piece in a mechanical linkage used especially in transforming rotary motion into linear motion or vice versa. It is often a part of a rotating wheel (e.g. an eccentric wheel) or shaft (e.g. a cylinder with an irregular shape) that strikes a lever at one or more points on its circular path. The cam can be a simple tooth, as is used to deliver pulses of power to a steam hammer, for example, or an eccentric disc or other shape that produces a smooth reciprocating (back and forth) motion in the *follower*, which is a lever making contact with the cam. The cam can be seen as a device that translates from circular to reciprocating (or sometimes oscillating) motion. A common example is the camshaft of an automobile, which takes the rotary motion of the engine and translates it into the reciprocating motion necessary to operate the intake and exhaust valves of the cylinders. The opposite operation, translation of reciprocating motion to circular motion, is done by a crank. An example is the crankshaft of a car, which takes the reciprocating motion of the pistons and translates it into the rotary motion necessary to operate the wheels. Cams can also be viewed as information-storing and -transmitting devices. Examples are the cam-drums that direct the notes of a music box or the movements of a screw machine's various tools and chucks. The information stored and transmitted by the cam is the answer to the question, "What actions should happen, and when?" (Even an automotive camshaft essentially answers that question, although the music box cam is a still-better example in illustrating this concept.) Certain cams can be characterized by their displacement diagrams, which reflect the changing position a roller follower would make as the cam rotates about an axis. These diagrams relate angular position to the radial displacement experienced at that position. Several key terms are relevant in such a construction of plate cams: base circle, prime circle (with radius equal to the sum of the follower radius and the base circle radius), pitch curve which is the radial curve traced out by applying the radial displacements away from the prime circle across all angles, and the lobe separation angle (LSA - the angle between two adjacent intake and exhaust cam lobes). Displacement diagrams are traditionally presented as graphs with non-negative values. A camshaft is a shaft to which a cam is fastened or of which a cam forms an integral part. 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.

Figure 1.1 Computer animation of a camshaft operating valves

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In internal combustion engines with pistons, the camshaft is used to operate poppet valves. It then consists of a cylindrical rod running the length of the cylinder bank with a number of oblong lobes protruding from it, one for each valve. The cams force the valves open by pressing on the valve, or on some intermediate mechanism as they rotate. Camshafts can be made out of several different types of material. These include; Chilled iron castings: this is a good choice for high volume production. A chilled iron camshaft has a resistance against wear because the camshaft lobes have been chilled, generally making them harder. When making chilled iron castings, other elements are added to the iron before casting to make the material more suitable for its application. Billet Steel: When a high-quality camshaft is required, engine builders and camshaft manufacturers choose to make the camshaft from steel billet. This method is also used for low volume production. This is a much more time-consuming process, and is generally more expensive than other methods. However, the finished product is far superior. When making the camshaft CNC lathes, CNC milling machines and CNC camshaft grinders will be used. Different types of steel bar can be used. One example is EN40b. When manufacturing a camshaft from EN40b, the camshaft will also be heat treated. the method of heat treatment is gas nitriding, which changes the micro-structure of the material. It gives a surface hardness of 55-62 on the HRC. These types of camshafts can be used in high performance engines. The relationship between the rotation of the camshaft and the rotation of the crankshaft is of critical importance. Since the valves control the flow of air/fuel mixture intake and exhaust gases, they must be opened and closed at the appropriate time during the stroke of the piston. For this reason, the camshaft is connected to the crankshaft either directly, via a gear mechanism, or indirectly via a belt or chain called a timing belt or timing chain. In some designs the camshaft also drives the distributor and the oil and fuel pumps. Also, on early fuel injection systems, cams on the camshaft would operate the fuel injectors. Ina two-stroke engine that uses a camshaft, each valve is opened once for each rotation of the crankshaft; in these engines, the camshaft rotates at the same rate as the crankshaft. In a four-stroke engine, the valves are opened only half as often; thus, two full rotations of the crankshaft occur for each rotation of the camshaft. The timing of the camshaft can be advanced to produce better low end torque or it can be retarded to produce better high end torque. Duration can often be confusing because manufacturers may select any lift point to advertise a camshaft's duration and sometimes will manipulate these numbers. The power and idle characteristics of a camshaft rated at .006" will be much different than one rated the same at .002". Whenever duration is quoted, be sure to note the lift at which it is given. Many performance engine builders gauge a race profile's aggressiveness by looking at the duration at .020", .050" and .200". The .020" number determines how responsive the motor will be and how much low end torque the motor will make. The .050" number is used to estimate where peak power will occur, and the .200" number gives an estimate of the power potential. In general, duration determines how many crankshaft degrees a camshaft maintains more than a given tappet lift. Depending on the location of the camshaft, the cams operate the valves either directly or through a linkage of pushrods and rockers. Direct operation involves a simpler mechanism and leads to fewer failures, but requires the camshaft to be positioned at the top of the cylinders. In the past when engines were not as reliable as today this was seen as too much bother, but in modern gasoline engines the overhead cam system, where the camshaft is on top of the cylinder head, is quite common. Some engines use two camshafts each for the intake and exhaust valves; such an arrangement is known as a double or dual overhead cam (DOHC), thus, a V engine may have four camshafts. The rockers or cam followers sometimes incorporate a mechanism to adjust and set the valve play through manual adjustment, but most modern auto engines have hydraulic lifters, eliminating the need to adjust the valve lash at regular intervals as the valvetrain wears, and in particular the valves and valve seats in the combustion chamber. Sliding friction between the surface of the cam and the cam follower which rides upon it is considerable. In order to reduce wear at this point, the cam and follower are both surface hardened, and modern lubricant motor oils contain additives specifically to reduce sliding friction. The lobes of the camshaft are usually slightly tapered, causing the cam followers or valve lifters to rotate slightly with each depression, and helping to distribute wear on the parts. The surfaces of the cam and follower are designed to "wear in" together, and therefore when either is replaced, the other should be as well to prevent excessive rapid wear. In some engines, the flat contact surfaces are replaced with rollers, which eliminate the sliding friction and wear but adds mass to the valvetrain. The camshaft uses lobes (called cams) that push against the valves to open them as the camshaft rotates; springs on the valves return them to their closed position. This is a critical job, and can have a great impact on an engine's performance at different speeds. On the next page of this article, you can see the animation we built to really show you the difference between a performance camshaft and a standard one. In this article, you will learn how the camshaft affects engine performance. We've got some great animations that show you how different engine layouts, like single overhead cam (SOHC) and double overhead cam (DOHC), really work. And then we'll go over a few of the neat ways that some cars adjust the camshaft so that it can handle different engine speeds more efficiently. The key parts of any 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. To

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understand why this is the case, imagine that we are running an engine extremely slowly -- at just 10 or 20 revolutions per minute (RPM) -- so that it takes the piston a couple of seconds to complete a cycle. It would be impossible to actually run a normal engine this slowly, but let's imagine that we could. At this slow speed, we would want cam lobes shaped so that: Just as the piston starts moving downward in the intake stroke (called top dead center, or TDC), the intake valve would open. The intake valve would close right as the piston bottoms out. The exhaust valve would open right as the piston bottoms out (called bottom dead center, or BDC) at the end of the combustion stroke, and would close as the piston completes the exhaust stroke. When you increase the RPM, the 10 to 20 RPM configuration for the camshaft does not work well. If the engine is running at 4,000 RPM, the valves are opening and closing 2,000 times every minute, or 33 times every second. At these speeds, the piston is moving very quickly, so the air/fuel mixture rushing into the cylinder is moving very quickly as well. 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. 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. Any given camshaft will be perfect only at one engine speed. At every other engine speed, the engine won't perform to its full potential. A fixed camshaft is, therefore, always a compromise. This is why carmakers have developed schemes to vary the cam profile as the engine speed changes. There are several different arrangements of camshafts on engines. We'll talk about some of the most common ones. You've probably heard the terminology: Single overhead cam (SOHC)

Double overhead cam (DOHC) 4

Pushrod

1.3 Camshaft Configurations:

The camshaft consists of a cylindrical rod running the length of the cylinder bank with a number of cams along with length one for each valve.

1.3.1 Single Overhead Cam

This arrangement denotes an engine with one cam per head. So, if it is an inline 4-cylinder or inline 6-cylinder engine, it will have one cam; if it is a V-6 or V-8, it will have two cams (one for each head).

The cam actuates rocker arms that press down on the valves, opening them. Springs return the valves to their closed position. These springs have to be very strong because at high engine speeds, the valves are pushed down very quickly, and it is the springs that keep the valves in contact with the rocker arms. If the springs were not strong enough, the valves might come away from the rocker arms and snap back. This is an undesirable situation that would result in extra wear on the cams and rocker arms.

On single and double overhead cam engines, the cams are driven by the crankshaft, via either a belt or chain called the timing belt or timing chain. These belts and chains need to be replaced or adjusted at regular intervals. If a timing belt breaks, the cam will stop spinning and the piston could hit the open valves.

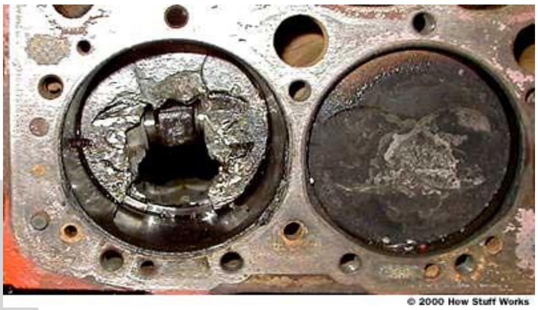

Figure 1.2 piston damage striking a valve

The picture above shows what can happen when a piston hits an open valve.

1.3.2 Double Overhead Cam

A double overhead cam engine has two cams per head. So inline engines have two cams, and V engines have four. Usually, double overhead cams are used on engines with four or more valves per cylinder -- a single camshaft simply cannot fit enough cam lobes to actuate all of those valves.

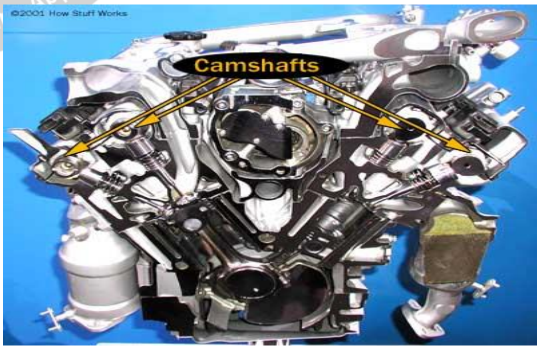

Figure 1.3 DOHC arrangement

The main reason to use double overhead cams is to allow for more intake and exhaust valves. More valves means that intake and exhaust gases can flow more freely because there are more openings for them to flow through. This increases the power of the engine. The final configuration we'll go into in this article is the pushrod engine.

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1.3.3 Pushrod Engines

Like SOHC and DOHC engines, the valves in a pushrod engine are located in the head, above the cylinder. The key difference is that the camshaft on a pushrod engine is inside the engine block, rather than in the head.

Figure 1.4 Pushrod engine

The cam actuates long rods that go up through the block and into the head to move the rockers. These long rods add mass to the system, which increases the load on the valve springs. This can limit the speed of pushrod engines; the overhead camshaft, which eliminates the pushrod from the system, is one of the engine technologies that made higher engine speeds possible.

The camshaft in a pushrod engine is often driven by gears or a short chain. Gear-drives are generally less prone to breakage than belt drives, which are often found in overhead cam engines.

1.4 Manufacturing Process

Figure 1.4.1 Step by step manufacturing process of camshaft

Step 1: The process of creating a camshaft begins with raw 8620 billet steel.
Step 2: The raw steel ranges from 2.125" to 2.5" in diameter and are 20ft in length.
Step 3: The raw steel bars are then turned on a lathe to remove the rough surface and then cut into the proper lengths depending on the engine size.

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Step 4: At this stage, the steel begins the process of becoming a camshaft as both the journals and lobes are cut and evenly spaced out.
Step 5: The Camshafts are then stack up and are prepared for the copper plating.
Step 6: The copper plating is done to keep the steel from becoming brittle and helps straighten the camshaft after the heat-treating process.
Step 7: Once the copper is applied, the journals are lathe down to the thickness that is needed.
Step 8: This process creates a smooth finish.
Step 9: Next, a special lobe milling machine is used to create the lift for the cam. These CNC machines use computerize programs that allow the manufacture to create the desired lobe and are precise at 0.0001 of an inch.
Step 10: Once the cams are roughly cut, they are placed in a furnace for heat treating. This process hardens the steel making the cam less likely to warp or snap when put under the stress of an engine.
Step 11: After the heat treating, the journals go through their final grounding stage and are milled to the correct dimensions.
Step 12: Following the journals are the lobes. They are grounded and polished to provide a smooth surface which reduces friction in the engine, freeing up horsepower.
Step 13: The last process uses a computerized scanner that checks the tolerances on the cams. Making sure that every lobe and journal are exactly the same.

A.S. Dhavale, V.R. Muttagi studied Modeling and Fracture Analysis of camshaft to design good mechanism linkages the dynamic behavior of the components must be considered, this includes the mathematical behavior of physical model. In this case, introduction of two mass, single degree of freedom and multiple degree of freedom dynamic models of cam follower systems are studied. The failure is occurred as sudden fracture at very close to journal location, where there is a stress concentration. The main reason of the fracture is determined as a casting defect and the camshaft of vehicles manufactured from that particular series of camshaft should be replaced. Also, nondestructive testing procedures of the component supplier should also be improved as the defect can easily be detectable by standard nondestructive techniques.

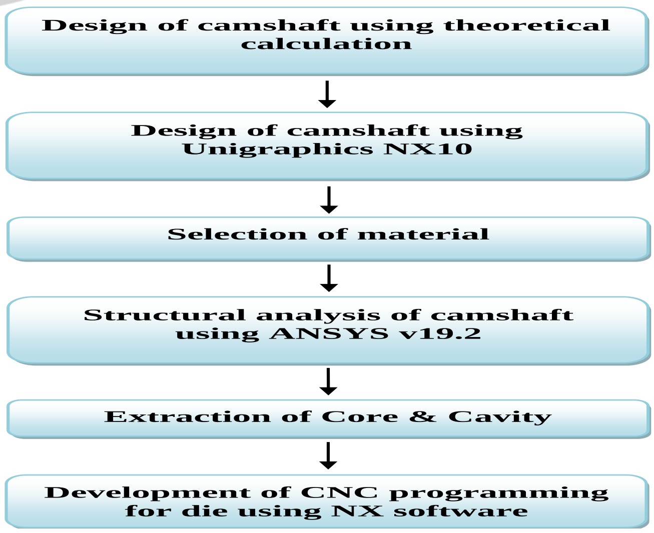
R. Mahesh, Mali1, D. Prabhakar presented Design Optimization of Cam & Follower Mechanism of an Internal Combustion Engine for Improving the Engine Efficiency. In this work an attempt is made to change the flat face of follower to a curved face follower, so that the required point contact can be achieved. As line contact between existing cam and follower mechanism results in high frictional losses which results in low mechanical efficiency. It is observed that the frequency of vibration in the existing and modified cam and follower mechanism remains almost same. This indicates change of the flat face of roller follower to a curved face roller follower mechanism results in low frictional losses due point contact which results in improved in mechanical efficiency of internal combustion engine by 65% to 70%.

Sudheer Y, Raghunatha Reddy C Variable Valve Actuation Introduction Conventional engines are designed with fixed mechanically-actuated valves. The position of the crankshaft and the profile of the camshaft determine the valve events (i.e, the timing of the opening and closing of the intake and exhaust valves). Since conventional engines have valve motion that is mechanically dependent on the crankshaft position, the valve motion is constant for all operating conditions. The ideal scheduling of the valve events, however, differs greatly between different operating conditions. This represents a significant compromise in an engine's design. 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 (autoignition). 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

II. METHODOLOGY

In the analyze procedure of camshaft by the static and structural analysis by finite element method for the various load of the material with their composition. In this for the various load of material find the stress development and also corresponding strain in the material also thermal strain development for various pressure and inertial forces in the material.

The overall work is divided into the following number of sub steps. The Figure 3.1 shows design procedure and analysis of camshaft



The Figure 3.1 shows design procedure and analysis of camshaft.

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1. In the first step design of camshaft is done based on theoretical calculation.
2. 3D model of camshaft is designed using Unigraphics NX10 software.
3. Based on required properties material is selected for camshaft.
4. Structural analysis of camshaft is determined by using ANSYS V19.2 software
5. Core & Cavity is extracted for the cam shaft using NX design software.
6. CNC program is developed for die using NX design software.

III. DESIGN CALCULATIONS

Cam design:

Designing cam for PS 24/2 stationary engine

Bore diameter: 127mm

Stroke length: 146.05mm

- Diameter of cam shaft = 0.16 X Bore X 12.7 =0.16 X 127 X 12.7 = 258.064mm
- Base circle diameter of cam lobe = 3 + camshaft diameter + 20 = 3 + 258.064 + 20 = 281.064mm
- Width of cam lobe = (0.09 X bore) + 6 mm = (0.09 X 127) + 6 = 29.22 mm
- Taking angle between cam lobes = 108^0 (for narrow cam lobes)

Total fore acting on cam lobe:

Consider d_P= 0.435 X d = 0.435 X 127 = 55.245mm

d_S= (d_P/8) + 6.35 = (55.245/8) + 6.35 = 13.255mm

P_{max} = 0.60505 MPa (for cam angle ϴ=135°) = 0.60505 N/mm²

We know that, t = K X d_P X $\sqrt{(P_{max} / f_t)}$

= 0.44*55.245*√(0.60505/56)

=0.44*55.245*0.10394

=2.41181

$$f_t = \frac{1.4F}{t^2}\left(1 - \frac{2d_s}{3d_p}\right)$$

$$56 = \frac{1.4F}{2.41181^2}\left(1 - \frac{2*13.255}{3*55.245}\right)$$

$$\frac{1}{F} = \frac{1.4}{56 * 2.41181^2}(0.159954)$$

$$\frac{1}{F} = 0.000752112$$

F = 1329.58N

Valve lift L= d_p/4

= 55.24/4

= 13.811mm

Spring elastic force F_e = L*K

= 13.811*0.42

= 5.8006N

Total force acting on the cam = 1329.5892 - 5.8006 = 1323.78861N

MODELING

6.3 3D MODEL OF CAMSHAFT

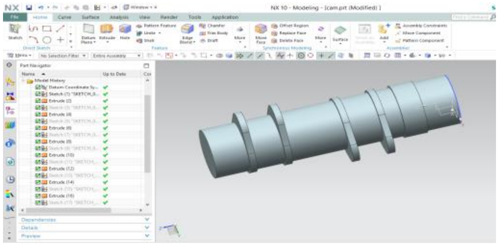

Fig.6.3.1 3D model of camshaft in NX software

Dimensions of camshaft

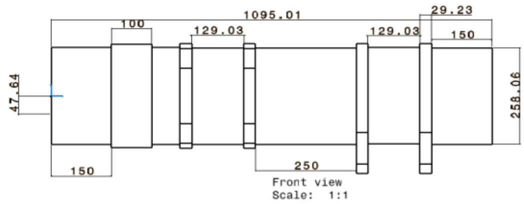

Fig 6.3.2 Front view of cam shaft

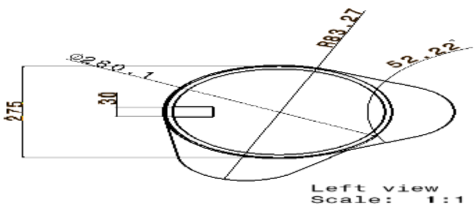

Fig 6.3.3 left side view of cam shaft

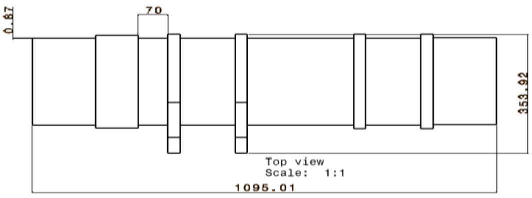

Fig 6.3.4 Top view of cam shaft

7.5 SELECTION OF MATERIAL

Based on the properties like strength, density, young's modulus and Poisson's ratio suitable material is selected. In the below table properties of material like structural steel & aluminium are given.

Table 7.1 Material properties

Material	Young's Modulus (MPa)	Density (Kg/mm³)	Poisson's Ratio	Strength (MPa)
Structural steel	200000	0.00000787	0.313	290
Aluminum 7475	70300	0.00000281	0.33	490

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STATIC STRUCTURAL ANALYSIS OF CAM SHAFT

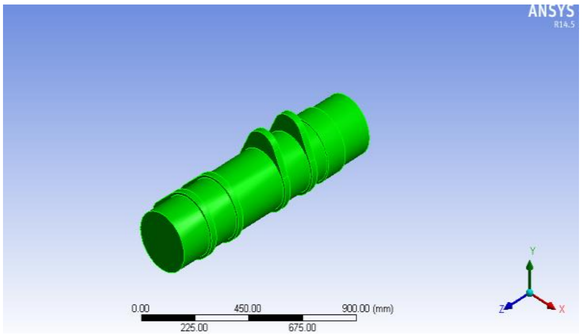

Fig 7.1 Model Imported

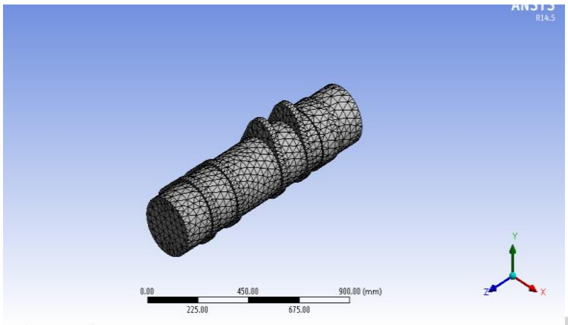

Fig 7.2 Meshed Model

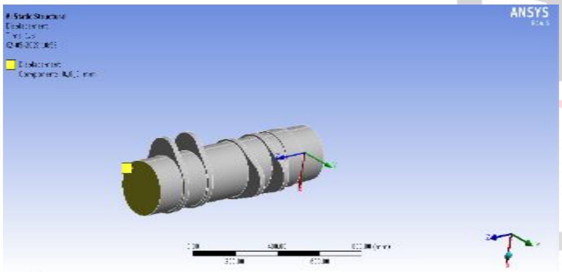

Fig 7.3 Displacement applied to camshaft

Select pressure → select required area → click on apply → enter pressure value→

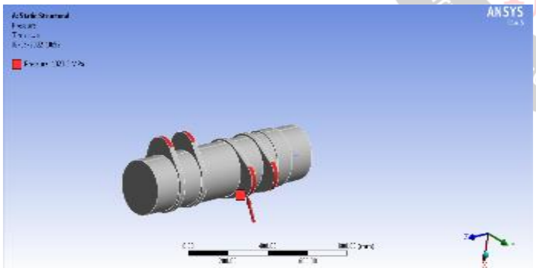

Fig 7.4 Pressure applied on cam profile

ALUMINIUM ALLOY 7475

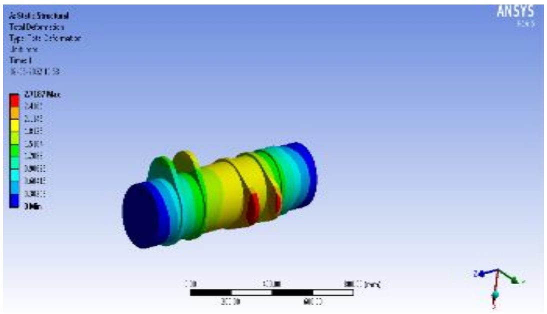

Fig 7.5 Total deformation for Al 7475

STRUCTURAL STEEL

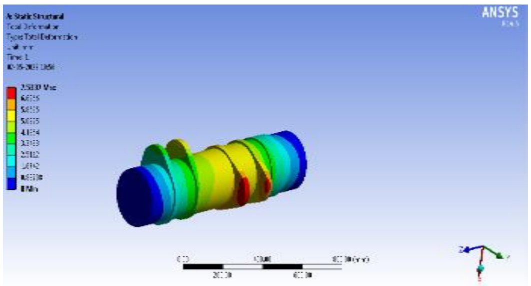

Fig 7.8 Total deformation for Steel

IV. RESULTS AND DISCUSSION

The model which is created in Unigraphics is analyzed using ANSYS software. Two different materials such as structural steel and Al 7475 has been considered. The deformation, stress & strain values are given in the table 8.1. The variation of deformation, stress and strain values are shown in figure 8.2 – 8.4 respectively.

Table 8.1 Deformation, stress, strain values using ANSYS software

Material	Deformation (mm)	Stress (Mpa)	Strain (Mpa)
Al 7475	2.718	1742.6	0.00871
Structural steel	7.532	1761.1	0.024

Fig 8.2 Deformation

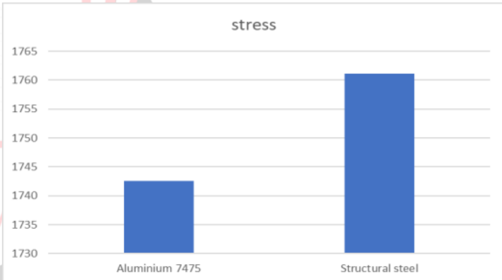

Fig 8.3 Stress

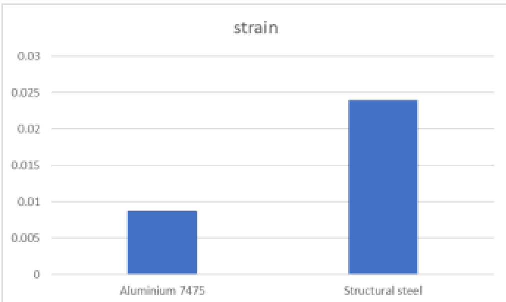

Fig 8.4 Strain

According to the results shown above, the aluminum alloy 7475 material is capable of withstanding more stress and less deformation and strain values.

Table 9.1 Die and component material and hardness for various cast metals

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Die component	Cast metal					
	Tin, lead & zinc		Aluminum & magnesium		Copper & brass	
	Material	Hardness	Material	Hardness	Material	Hardness
Cavity inserts	P20[note 1]	290–330 HB	H13	42–48 HRC	DIN 1.2367	38–44 HRC
	H11	46–50 HRC	H11	42–48 HRC	H20, H21, H22	44–48 HRC
	H13	46–50 HRC				
Cores	H13	46–52 HRC	H13	44–48 HRC	DIN 1.2367	40–46 HRC
			DIN 1.2367	42–48 HRC		
Core pins	H13	48–52 HRC	DIN 1.2367 prehard	37–40 HRC	DIN 1.2367 prehard	37–40 HRC
Sprue parts	H13	48–52 HRC	H13 DIN 1.2367	46–48 HRC 44–46 HRC	DIN 1.2367	42–46 HRC
Nozzle	420	40–44 HRC	H13	42–48 HRC	DIN 1.2367 H13	40–44 HRC 42–48 HRC
Ejector pins	H13	46–50 HRC	H13	46–50 HRC	H13	46–50 HRC
Plunger shot sleeve	H13	46–50 HRC	H13 DIN 1.2367	42–48 HRC 42–48 HRC	DIN 1.2367 H13	42–46 HRC 42–46 HRC
Holder block	4140 prehard	~300 HB	4140 prehard	~300 HB	4140 prehard	~300 HB

The main failure mode for die casting dies is wear or erosion. Other failure modes are *heat checking* and *thermal fatigue*. Heat checking is when surface cracks occur on the die due to a large temperature change on every cycle. Thermal fatigue is when surface cracks occur on the die due to a large number of cycles.

Table 9.1.2 Typical die temperatures and life for various cast materials

Materials	Zinc	Aluminum	Magnesium	Brass (leaded yellow)
Maximum die life [number of cycles]	1,000,000	100,000	100,000	10,000
Die temperature [C° (F°)]	218 (425)	288 (550)	260 (500)	500 (950)
Casting temperature [C° (F°)]	400 (760)	660 (1220)	760 (1400)	1090 (2000)

9.1 Process

9.2 Inspection

9.3 Lubricants

9.4 Variants

9.4.1 Acurad

9.4.2 Pore-free

9.4.3 Heated-manifold direct-injection

9.4.4 Semi-solid

9.5 Advantages and disadvantages of die casting

9.5.1 Advantages of die casting:

9.5.2 Disadvantages of die casting:

9.6 Design aspects of die casting

9.7 Core and Cavity

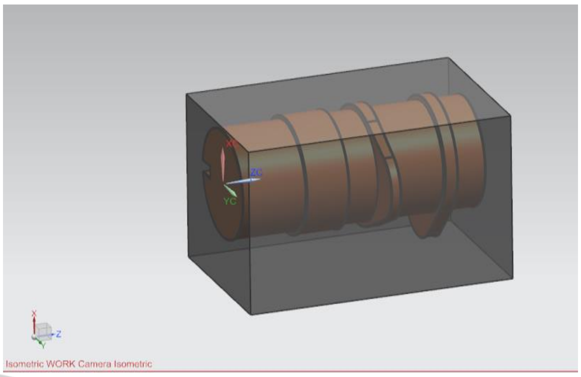

Fig 10.4 Camshaft with work piece

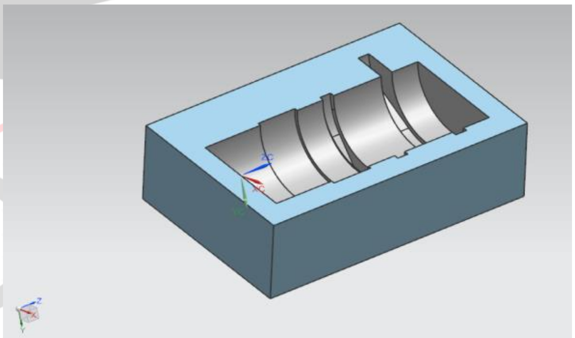

Fig 10.6 Cavity1 region

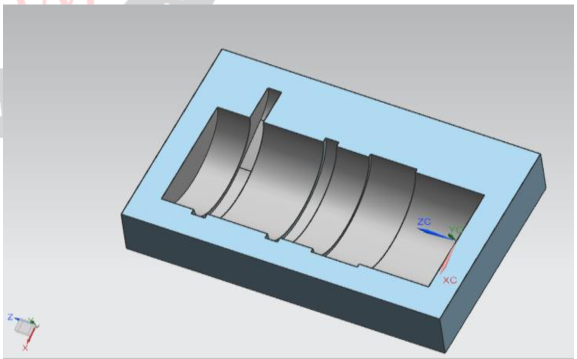

Fig 10.7 Cavity2 region

V. CONCLUSION

In this paper, a cam shaft is designed by using theoretical calculations and modeled in NX. Static structural analysis of Structural Steel and Aluminum alloy 7475 materials on the camshaft is done using Ansys. By observing the stress values, they are less than their respective yield stress values for all the materials. So deigned cam shaft is safe. T2he main advantage of using Aluminum alloys is its less density

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so the weight of cam shaft is less when compared with that of Steel.

- Deformation induced in AL 7475 is 64% less than the structural steel.
- Stress induced in AL 7475 is 1.05% less than the structural steel.
- Stain induced in AL 7475 is 64% less than structural steel.

Core & Cavity is extracted for the cam shaft and CNC Program is generated for both core and cavity using NX design software. A prototype of the cam shaft is manufactured by preparing the die and casting process.

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