FINITE ELEMENT ANALYSIS AND MODAL ANALYSIS OF CAMSHAFT USING ANSYS SOFTWARE

DISSERTATION- II

Submitted in Partial Fulfilment of the
Requirement for Award of the Degree
Of

MASTER OF TECHNOLOGY
In
MECHANICAL ENGINEERING

By

Dinesh Kumar
(11004966)

Under the Guidance of

Mr. Nitin Chauhan

DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY
PHAGWARA, PUNJAB (INDIA) -144411
2014 - 2015

LOVELY PROFESSIONAL UNIVERSITY

CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation-II entitled **“Finite Element Analysis and Modal Analysis of Camshaft Using ANSYS Software”** partial fulfilment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation under the supervision of **Mr. Nitin Chauhan**, **Assistant Professor**, Department of Mechanical Engineering, Lovely Professional University,
Punjab.

The matter presented in this Dissertation-II has not been submitted by me anywhere for the award of any other degree or to any other institute.

Date:

Dinesh Kumar

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

Date:

Mr. Nitin Chauhan

Supervisor

M-Tech Dissertation-II examination of **Finite Element Analysis and Modal Analysis of Camshaft Using ANSYS Software**, has been held on

Signature of Examiner

ACKNOWLEDGEMENTS

I owe my deepest gratitude and respect to my mentor **Mr. Nitin Chauhan** for his continuous support and encouragement of this work. He is not only a knowledgeable and intelligent guide and teacher, but also a responsible and considerate human being. I have wondered more than once at his insight and Professionalism. I especially thank him for his understanding, patience, and guidance during the project. I will always be grateful for what I learned from him during my project.

It has been a great honour and privilege for me to know and work with my advisor. He is an extremely knowledgeable teacher who appreciates Science for the sake of science, and makes every effort to help his students see the beauty in learning and education. His modest and friendly behaviour raises every admiration and respect. He has generously shared with me his expertise and knowledge, and I are indebted to him for giving me the opportunity to talk to him regularly and for reviewing my work under his intense time constraints. This work would by no means be possible without his interesting ideas, insights, and suggestions.

I would like to extend my most sincere thanks to my friends at lovely professional university for their group effort and friendship.

I would like to thank my wonderful friends in LPU and elsewhere for their encouragements, and for making my project a memorable experience on the social front.

I am boundlessly grateful to my entire family for their love and never-ending support. I especially thank my parents.

- **Dinesh Kumar**

TABLE OF CONTENTS

List of tables:

List of figures:

List of equations:

Nomenclature:

CHAPTER -1

1 INTRODUCTION

In internal combustion engine camshaft is use to transfer motion between inlet and exhaust valve. Since the opening and closing of valves is so important in IC engine therefore it is very important to optimize the component which is providing that motion if the motion is not precise then the performance of engine will be degrade. Therefore it is very important to analyse the component that includes the mathematical behaviour and model of the 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. For a Four stroke engine camshaft is the most important component in the performance of engine. Camshaft is such an important part of engine that the researchers have spent years to design a precise and accurate camshaft that may transfer the exact motion to the valves. In the presented work the cause of fracture and the exact loading conditions of camshaft are discussed. By using scanning electron microscopy and finite element analysis methods are used for fracture analysis of camshaft. The camshaft rotates half times the crankshaft or once per four-cycle stroke. The camshaft may operate the: Valve train, Mechanical fuel pump, Oil pump, Distributor, Major function is to operate the valve train. The lobes on the cam open the valves against the pressure of the valve springs. Bearing journal can be internally or externally lubricated (oiled).

1.1 Classification:

Camshafts are of one of four types:

- Hydraulic flat-tappet
- Hydraulic roller
- Solid flat-tappet
- Solid roller

1.1.1 Hydraulic flat-tappet

The lifter is “spring” and oil loaded to allow for compensation. It is of Traditional O.E. style (1950’s – mid 90’s).Used with flat or convex-faced lifters, generally cast iron or hardened steel is used to made these camshafts. Requires a “break-in” period to establish a wear pattern. Cast-iron cams are finished with a phosphate coating. These are mainly Steel cams (SAE 4160 or 4180) are hardened by Induction hardening – heated cherry-red in an electric field then oil cooled. Liquid nitriding – hardens to .001 to .0015 Gas nitriding– hardens to .004 to .006 thickness.

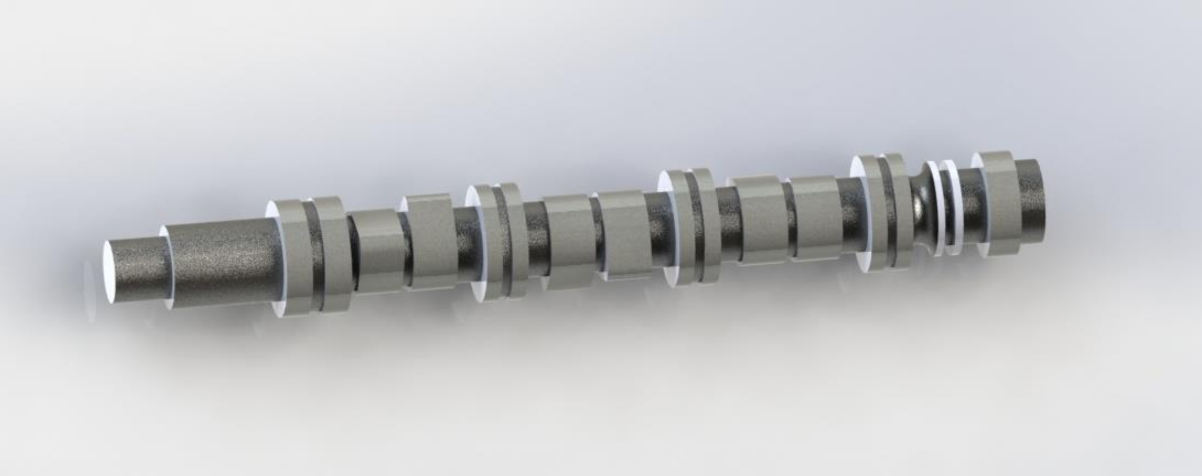


Figure 1: The actual CAD model of camshaft

1.1.2 Hydraulic Roller

The camshaft is generally made of non-hardened steel. The lobes must be “finished” by the manufacturer prior to assembly there is no “break-in period”.

1.1.3 Solid Flat-tappet and Roller

In solid flat tappet and roller camshaft No internal hydraulic absorption present in the material of the cam allowing more consisting valve lift, especially at high RPM. It creates noise in low temperatures, therefore more frequent and accurate valve-lash adjustments is required. Oil is diverted by the help of the pushrods along a pushrod seat. Lifter preload is not required only valve lash is calculated .Lash values may be given hot or cold.Typical values range calculated is from .002 - .005’’.

In the automobile industry to provide the lower emission, lower fuel consumption high performance and long life service for a component is very hard. That’s why product development of existing parts and product systems is important. However, while making calculation models of engine parts, one can’t predict the exact conditions in which the product would be working.

A kinematic pair of cam - follower works under complicated conditions of environmental and mechanical load, and wears during operation. The contact surfaces of the cam and the follower are usually surface hardened. The hardening may be due to phase transformation or precipitation processes occurring in the material during heat treatment or thermo chemical treatment. The automotive sector has reached a very high production capacity in the last decades. Depending on this increasing capacity, its stable growth is anticipated in the world economy. In high cycle fatigue, as the cyclic stress is comparatively low, a large fraction of the fatigue life is used in micro crack initiation. Wear is another major failure of engine camshaft material. Putting all these failure criteria aside there is another problem that has been detected in the camshafts and that is the ‘vibration’ in the exact loading conditions. There are vibrations in the camshaft while operation on the engine head due to which the performance of the engine may be disturbed. Here in the present work we have tested various materials and models of camshafts and find the results for the free vibrations forced vibrations and the total deformation in the same. Here, petrol engine camshaft is made up from the EN 8D (Mild steel), EN24, EN28, structural steel and chilled cast iron has been tested, so we apply von-mises criteria. For the purpose of static structural analysis we are using ANSYS 14.5 workbench. By using this software we show the maximum stress, maximum strain and total deformation at different natural frequencies and different RPM.

1.2 Valve Train Sub-Assembly:

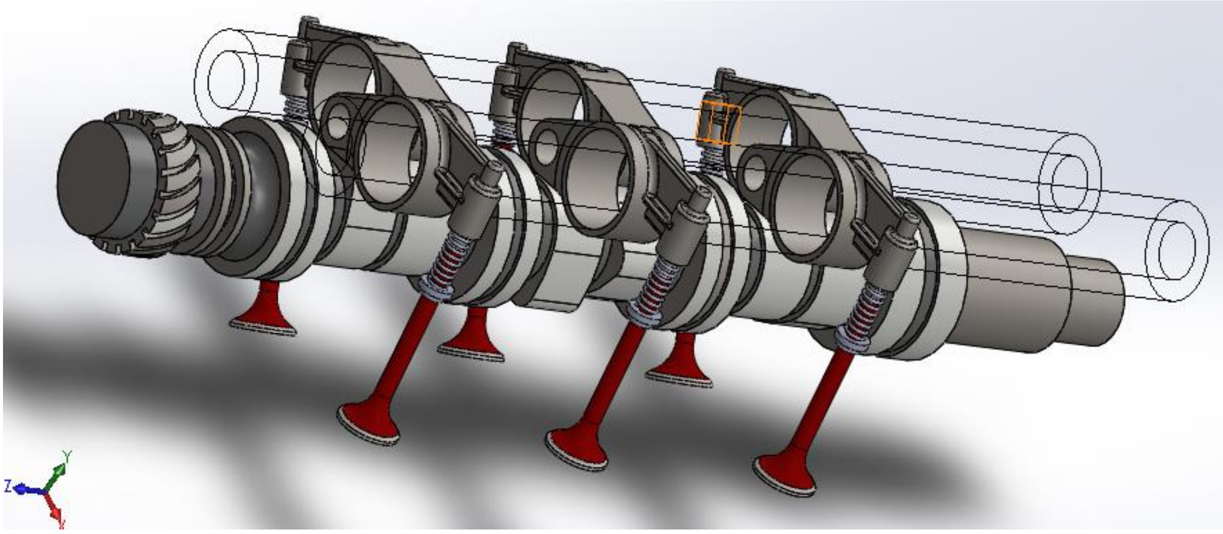


Figure 2: Showing the valvetrain assembly of engine head.

The valve train in an engine is used to regulate the valve opening and closing at the inlet and exhaust stork of the crank shaft (piston TDC and BDC). Mainly the timing of the engine is regulated by the valve train assembly so that the firing order would be in such a way that there will be only one piston firing at a time. The lobes were rotated in such a way so that the 2nd, 3rd, and 4th lobes were 90°, 270° and 180° from the 1st lob respectively. This angular difference from each cam assembly to the next causes each piston to fire at a time when no other piston is firing. SOHC is called Single Overhead Cam Assembly i.e. the cam is on the head of the engine. And is single operated. To allow the appropriate motion, the cam-follower mechanisms was defined for each cam and rocker combinations.

Key Words: Camshaft, Failure analysis, Stress analysis, Dynamic models, SOHC, Valve train

Kinematic pair, lobes.

CHAPTER -2

2 REVIEW OF LITERATURE

In this portion the different views of different authors has been discussed on the mechanism, design and optimization of a camshaft. Camshaft is a main part of the engine. It acts like a brain of the engine as it regulates the opening and closing of the intake and the exhaust valve. It is situated on the top head of the engine where it is covered by a cover called tappet cover. It is generally being correlated by the timing of the engine as it also regulates the timing of the valves i.e.- it determines for how long the exhaust valve should closed and for how long the intake valve should be opened for a intake stroke and same for the power and the exhaust stroke. Therefore the camshaft must be optimized and designed in such a manner so that there would be no harm to the engine performance and to the vehicle as well. Now a days it is a common problem for a vehicle i.e. the failure of the cam shaft, or the camshaft heating and fracture of camshaft. So to prevent these problem I am going to discuss some of the main research and experiment done on the camshaft design till date.

Chyuan et. al [1]*:* In this paper he had investigated the 16 valve twin cam shaft engine block head structure during the firing and assembly load conditions using the CAE tool I-DEAS and observed the results-

i) Firing load case: The firing gas load had been applied to the cylinder head to represent the maximum cylinder pressure.

Maximum displacement of 0.0356 mm in cylinder structure and maximum principle stress of 6.25 kgf/mm² between the inlet valve seat and exhaust valve seat were obtained under the local bending moment value of 8.26 kgf/mm².

ii) Assembly load case: an assembly load has been applied which comprises the valve seat insert bolt insertion bolt per load and cold assembly loads.

Maximum displacement in the cylinder structure of 0.178 mm and a maximum principle stress of 25 kgf/mm² were obtained under the local bending moment of 28.80 kgf/mm².

iii) Assembly – gas combined case: when both loading conditions have been applied combined then a maximum displacement of 0.200mm in the cylinder head was obtained and a maximum principle of 25 kgf/ mm² were obtained under the local bending moment of 30.40 Kgf/mm².

Jean W. Zu etal [2]: In this paper he had optimized and designed a new cam drive engine model, first he had design the typical cam profile design by analysing the unique cam mechanism he had also discussed the contact stress, radius of curvature, and pressure angle as the constraints by considering the output torque as main objective of the design. Then he had compared the results and optimized it using the GA [3] (genetic algorithm) method for both conventional engine and the new cam drive engine. General polynomial spline [4] were used to represent the profiles of both intake cam and exhaust cam (stroke) which increased the mean torque by 18%. A modified spline equation called 'B-splines' [5] were used to increase the performance for investigation and it is improved by 24%.Moreover, the output torque generated by the best profiles increased by 28% compared to that generated by the initial profiles. At the same time, the smoothness of the best profiles was also comparable to that for the initial profiles.

Johnson et al [3]*:* In this article Johnson had presented the proper approach to designing an earn-follower system, and in the process also present some less than proper designs as examples of the problems which are faced by most of the inexperienced earn designers. He also had discussed the cam terminologies, cam motions and constraints. Some laws were also employed such as 'The cam function must be continuous through the first and second derivatives of displacement across the entire interval (360 degrees)'. 'The jerk function must be finite across the entire interval (360 degrees)'. In any but the simplest of cams, the cam motion program cannot be defined by a single mathematical expression, but rather must be defined by several separate functions, each of which defines the follower behaviour over one segment, or piece, of the cam. Expressions are sometimes called piecewise functions.

Dhavale et al [4]*:* In his work he had discussed the stress analysis and the fracture analysis of the cam shaft also depicted the importance of the cam shaft in an engine. Derived some relations and results by taking the specific material for the camshaft manufacturing also analysed the results using the finite element methods and software. He also prepared a dynamic model for FEA analysis. He had used the iron alloy with specific weight ratios of different elements as Carbon, Silicon, Manganese, Molybdenum, Nickel, Aluminium Copper, Titanium, Magnesium, Sulphur, Phosphorus, 3.42%, 2.33%, 0.296%, 0.010%, 0.038%, 0.010%, 0.518%, 0.028%, 0.026%, 0.009%, 0% respectively and remaining Ferrous was taken alone. The stress analysis of the camshaft was carried out for the determination of the stress concentration level at the fracture region by the finite element method. The failure is occurred as a sudden fracture at very close to journal location, where there was a stress concentration. The main reason of the fracture was determined as a casting defect. The failure was found to be related to production of the camshaft material.

Bagi et al [5]*:* In this paper they had proposed an idea to replace the conventional cam follower mechanism in present IC engines with theirs. They had made an attempt to replace the flat faced follower used in the current IC engines with the curved follower so that the better point contact between cam and follower could be achieved. Using this idea they not only reduced the relative friction between the cam and the follower but also improved the performance of the engine. It had also helped a lot in improving the mechanical efficiency of an engine. A finite element method and ANSYS being used to perform the analysis and generated the results. The obtained frequency range of existing roller follower was 828.32 Hz to 3272.8 Hz and for modified roller was 953.60 Hz to 3162.7 Hz and the Maximum values of deformation for modified roller follower was 21.675 mm, while for existing roller follower was 23.41 mm for the obtained frequency which results an improved mechanical efficiency of internal combustion engine of 65% to 70%.

Duque et al [6]*:* They had discussed the contact pressure generated between the camshaft and the roller follower and also compared the contact pressure generated between the camshaft and the roller follower of an iron casted cam shaft and an assembled camshaft. They also had suggested that the assembled camshaft was a good solution to reduce the weight and performance of the engine. They had also used the FEA (Finite Element Analysis) and FEM (Finite Element Methods) to design the desired camshaft model and analysis. First they had run some simulations on the ordinary camshaft to define an acceptable value of the contact pressure after which they introduced their assembled camshaft. After their investigations theory had suggested that the camshaft should be made of steel that should be induction hardened up to at least 1mm and up to 60-64 HRC and the roller should also made up of carburized steel with induction hardened up to at least .08mm. the also emphasized on the fact that the element type taken in the finite element analysis can also alter the results so much in numerical values.

Kumar et al [7]*:* In this paper they had also remodelled designed and analysed the cam shaft in FEM. They had discussed the techniques and methods to make the camshaft robust and versatile to all the possible loading conditions. They had also analysed the dynamic behaviour of the cam shaft during load conditions to calculate the exact load value for the camshaft operation. For the operation and force values they had employed the finite element method. From these operations they found maximum design strength is 240.6 N/mm2 from the material property given as Young's modulus 210000-210000 MPa, Tensile strength 600 - 800 MPa, Elongation 16 - 16 %, Yield strength 340 – 400 MPa the ultimate tensile strength of the material is 720 N/mm2, then the factor of safety becomes within that safety limits.

Escobar et al [8]*:* In their work they had employed a non-destructive testing [12] method for three 2.3L cam shafts in an engine simulator for an equivalent of 100,000 miles. They had employed various methods to draw the results such as optical microscopy, acoustic microscopy and profilometry [13]. But there were no evidence of any tribological effect due to the sliding friction of the follower. Generally they had investigated the surface roughness cracks, crack depth of at a general camshaft lobes. They had found the cracks of 300µm in length due to grinding of the lobes during fractography [14] testing. X-ray residual stress test [15] shown the evidence of residual stress relaxation. Moreover there were two type of cracks mainly found on the surface of the camshaft lobes straight and pitted. Straight cracks were nucleated due to the grinding operations and pitted cracks were due to impact and cyclic load generated by the follower during the testing. So they had suggested to re-hardening of the lobes and the follower to maintain the exact working conditions.

Singhose et al [9]*:* They had investigate the cause of unwanted vibration and force during the cam operation. Because unwanted vibration in cam-follower systems causes increased operating forces and costs. They also investigated the importance of the shape function of a cam profile. They had investigated the function using real-time command modification method. They also had manufactured the experimental apparatus for results and demonstration. A simple input shaping procedure was developed to modify cam profiles so that they do not excite a known vibration frequency. The final shaped cam profile results in no residual vibration of the follower. This was only applicable for the single speed cam but they also developed the extension for the variable speed operations.

Zhang et al [10]*:* In this paper they had optimized the camshaft grinding process parameters using GA (Genetic algorithm) and ANN (artificial neutral network) methods. GA is used to improve the accuracy and speed based on the ANN model. After the experiment they collected the samples that were designed by uniform design, six samples were collected from previous machining process to test the network. The errors to test the network by six testing data had a uniform distribution pattern about zero with a mean value and standard deviation of −0.05% and 7.46%, respectively. The result shows that 85.42% of the predicted values have the percentage error ranging between ±10percent. Hence they had concluded that the GA and ANN method can be used for the optimization of the grinding parameters of a camshaft.

Wanjari et al [11]***:*** In this paper they had discussed the various results on camshaft at different speed and loading conditions. They had also discussed the failure reasons and the factors affecting the performance of a camshaft, they have tried to change the material of the camshaft so that the thermal flux and the shear stresses may be balance in some satisfactory regions. They has found that the values of shear stress in grey cast iron is minimum. And the value of total deformation is low for forged steel. The maximum values of loads 3500N and 5000N they have obtained maximum value of shear stress and total deformation. These value of loads are obtained at initial / starting stage of the vehicle when it was running at 1650 to 1950 RPM. So they had recommended that, the vehicle should cross this range of engine speed as early as possible and the grey cast iron is the best material for manufacturing of camshaft.

Li Ping et al [12]***:*** They had performed an experiment with the camshaft made of chilled cast iron in this paper. They had installed the homemade casted chilled cast iron camshaft in a home-made Fukang car. The fracture had occurred only after running over a distance of 6,200 km. They had also discussed the cause of failure at microstructure level. The main reason for the fracture failure of the camshaft is that a too strong chilled trend existed in the transition region. The microstructure of fracture zone is Ledeburite, and its hardness is also beyond the range of the standard.

***S.G.Thorat* et al** [13] : they had done the camshaft analysis in the ANSYS software they have also calculated the loading conditions of the camshaft on the bases of the engine specifications they also have used the formulae for the total deformation in the camshaft for the FE analysis they have used ANSYS software for a load of 1134 N they were getting a deflection of .00059mm in the camshaft when they have used some specific material. They have compared the results those were calculated manually with the analytical those were calculated using software.

Kolchin-Demidov [14] *:* the book design of automotive engine is the key to calculate the exact loading conditions for the camshaft in this book they have provided the equations and the loading conditions for each components in the engine they have also considered the engine specifications in the loading and provide the exact equation for the solution.

Mohd H. Othman [15] : in his research he had analyse the frequency and the vibration of the cam and follower mechanism he had provide the method and the exact boundary conditions that may also applied to the system that is using the cam and follower mechanism. He had analyse the vibrations of the DYNACAM 1998 and also analyse the effect of the impact force on the vibrations of cam and follower.

Kothari et al [16] **:** they have calculated the deformation in the cam using the different material they had calculated the total deformation in the cam during the loading conditions using the ANSYS 12.1 software. They have calculated the total hydraulic pressure and the load on the cam due to the cylinder and calculated the deformation in cam they have calculated the total deformation in the exhaust cam inlet cam and the fuel cam simultaneously.

2.1 OUTCOMES

2.1.1 Summary:

From this literature review we now know that there are various fields on which we can explore the research i.e. – camshaft, they have done an anonymous work related to the fields. The work of each and every author is very informative and helpful but there are some fields where no one has worked yet. Some of the researchers had work in the fracture analysis of the camshaft they have calculated the maximum load that a camshaft can bare they have used different materials too such as chilled cast iron and stainless steels but they haven’t got the desired results there was always a some deficiency elated to the life of the camshaft. Then researchers have done some tribological analysis on the camshaft they have changed the behaviour and the nature of contact between the camshaft and follower they have replaced the flat follower to the round one, which improved the span and the lift of follower now camshaft was optimised and the wear and friction between cam and follower was reduced. Afterwards researchers have also developed an engine without camshaft which was a concept only but they have replaced the camshaft mechanism with some curved circular rotatory engine that was having the same timing diagram as the camshaft engine. In present scenario the vehicles are not using these camshafts they are using the electronic injection system which allows the user to set the timing electronically for the vehicle. But in the high performance vehicles they are still using the camshaft as the main part of engine because camshaft provides the reliability and durability with the mechanical point of view. In the present work the main focus of study is the camshaft and its vibrations with total deformation and calculation of the exact loading conditions of a camshaft.

2.1.1.1 Gaps in research:

The researchers have done a lot of work related to the camshaft they have calculated the maximum loads and the strength of camshaft, materials those can be used for the manufacturing of the camshaft. They have also calculated the lifespan of the component according to the researchers that we have gone through and almost we have gone through the all, they have done the work related to the material and the wear, smoothness, replacement and total change in mechanism related to camshaft. According to all the research and literature that is reviewed there is nothing done for the vibration control of the camshaft so there is a gap between these researches that is provided by the ‘Mahesh R. Mali1, Prabhakar D. Maskar, Shravan H. Gawande, Jay S. Bagi’ they have calculated the natural frequencies of the roller follower provided with the operating speed and pressure in Design Optimization of Cam & Follower Mechanism of an Internal Combustion Engine for Improving the Engine Efficiency, Journal of Modern Mechanical Engineering, vol. 2 / March 2012 [5]. They have purposed that if we are using the roller follower instead of the flat follower the natural frequency of the cam and follower can be reduced. So in the following work we have focused the research related to the vibration analysis of the camshafts of different materials those are available in the market and can be use as the raw material for the component.

We here are going to calculate and optimize the vibration causes and frequencies of camshaft with the total deformation and the results are then compared with each other using different materials.

CHAPTER-3

3 OBJECTIVE OF STUDY (PROBLEM FORMULATION)

- To calculate the actual loading conditions for the camshaft, during operation.
- **Vibration and FEA analysis of camshaft using ANSYS software.**

  We will be preparing a full SI engine valve train mechanism in the modelling softwares and analysing the vibration causes after calculating the causes and frequencies of the vibration we will be optimizing the vibrations by changing the material and try to find the most suitable material for camshaft manufacturing.

- **Increase the performance of an engine**

With the vibration control and optimization in the camshaft we can improve the engine performance, as vibration causes very large energy loss during the engine operation

3.1 SCOPE OF STUDY

With the help of this work that we are going to do here one can improve the performance, efficiency and life of any SI engine which uses the camshafts. This work may be helpful to calculate the exact loading and working conditions of camshaft in an engine. The main scope of this study is to calculate the total vibration in the camshaft and the various deformation mode shapes, those are calculated at different frequencies.

This research is also helpful in the field of vibration and friction analysis of cam and follower mechanism.

3.2 EXPECTED OUTCOMES

The material tested for the fabrication and design testing of the cam shaft i.e EN8 D/ EN24 steel is the suitable material for the camshaft manufacturing it has very effective torsional strength and having the properties that are suitable for the operation.

The natural frequencies are optimised and the engine performance is increased.

CHAPTER-4

4 RESEARCH METHODOLOGY

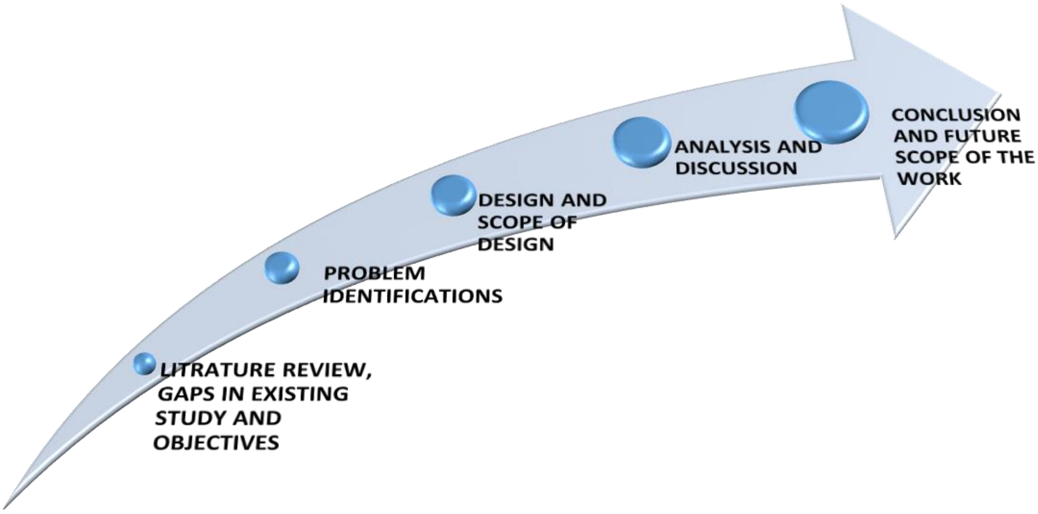


Figure 3: Research methodology and steps included in research

- **Literature review** is study of the research that has been done in the related field finding the gaps in that research and providing new or improving the existing research whereas
- **Problem identification** is the identification and formulation of the founded gaps in the research.
- **Design** is to design the existing and the new ideas in any design software and find out the future scopes and uses of the particular design

- **Analysis** is the part in which we test whether the component will work in the specific conditions or not with desired improvements and modifications. Mainly analysis in the design consists of three steps-

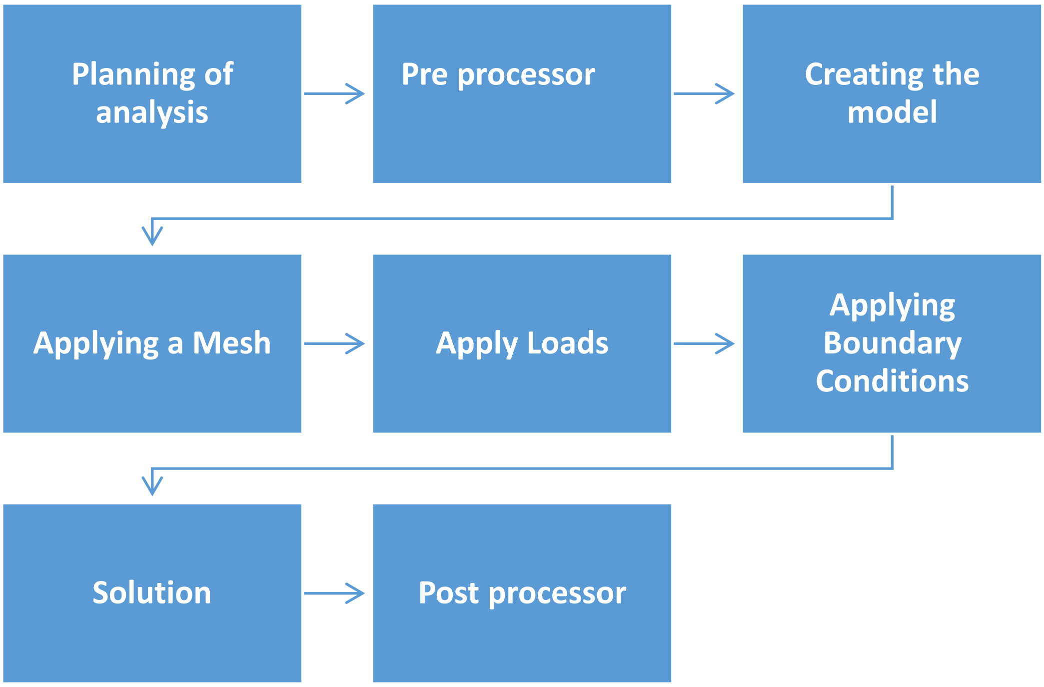


Figure 4: Analysis procedure and the steps involved in the process.

4.1 ANALYSIS PROCEDURE

In the real world, no analysis is typical, as there are usually facts that cause it to differ from others. There is however a main procedure that most FE investigations adopts. This procedure is detailed below:

4.1.1 Planning the Analysis

This is seemingly the most vital piece of any investigation, as it aides guarantee the achievement of the recreation. Strangely, it is typically the one analyst forgets. The main motive behind a FE examination is to model the behaviour of a structure under an arrangement of loads. To perform these analysis we have to consider the loads which are going to affect the model and we have to ignore the loads or facts which are not going to affect the final results. The extent of accuracy of the outcomes is very many dependants on the level of planning of the analysis that has been carried out. Answers of too many questions is needed to be found. Planning of the analysis deals with the extant of the results accuracy because better would be the planning more accurate will be the results.

4.1.2 Pre-Processor

Pre-processor in the general FE model analysis includes the name of the file, problem. Providing a name to a file is considered as the optional but it is very useful when you are dealing with the various analysis on the same project, it also provides the difference between the various iterations of the processes those are applied on the same base model. There are various type of analysis those can be used, e.g. structural, fluid, thermal or electromagnetic, etc. (sometimes this can only be done by selecting a particular element type).

4.1.3 Creating the model

The model is first drawn in the 2d sketch space in the appropriate units (M, mm, in, cm, ft. etc.) The model then is converted into the 3D space using the design softwares like Pro-E, Solidworks etc. then it can be imported to the another CAD drafting package by the neutral file formats like IGES, STEP, ACIS, Parasolid txt. DXF etc. if a model is created in the software with unit in mm for example then after importing the model the units of the model in the software should remain the same if it is not so the results may go out of scale and will not match the final expectations. This is the common mistake that is done by most of the analysers and don't even points out. Defining the element type, this may be 1D, 2D or 3Dand specific to the analysis type being carried out (you need thermal elements to do thermal analyses).

4.1.4 Applying a Mesh

There are three main type of meshing –

- **Structured meshing**

It is a mesh type which is characterized by its regular shape arrays of the elements which are connected to each other. They can be 2 dimensional or 3 dimensional elements. This restricts the element choices to quadrilaterals in 2 Dimensional or hexahedra in 3 Dimensional elements.

The regularity of the connectivity allows us to conserve space since neighbourhood relationships are defined by the storage arrangement.

- **Unstructured meshing**

It is a mesh type which is characterized by its irregular shape arrays of the elements which are connected to each other. This allows for any possible element that a solver might be able to use. Compared to structured meshes, the storage requirements for an unstructured mesh can be substantially larger since the neighbourhood connectivity must be explicitly stored.

- **Hybrid meshing**

In hybrid meshing the mesher includes the mixture of the element type it contains the structured and unstructured portion of meshing. This type of meshing requires the knowledge of both type of meshing in previous. Therefore it is also called the mixed type of meshing because it contains the element of the structured meshing type and the unstructured meshing in an array (presumably stored in an unstructured fashion).

Meshing is the process to use to divide a large model into the small discreet elements which have a defined shape and size that can be controlled by the user. There are several geometry having irregular shapes and sizes to calculate total deformation in such elements or to find the stress generated after load or to calculate various other results, it is very tedious task. To make all these part easy to calculate meshing is used it divides such geometry into small elements for which we have definite formulae and functions to calculate these results. Then all these results are being integrated to get the total solution for the geometry. One can control the size of the elements to get the fine meshing. The finer the mesh, the better are the results, but it also takes longer time to calculate the results. Therefore, we made a compromization between the accuracy and the solution speed usually. The mesh may be created manually, or generated automatically like the one that is shown below. When we create the meshing manually we have seen that the element size on the ends of the geometry are smaller in comparison to the other elements this is called the refinement of mesh size. Manual meshing is a long & tedious process for models with large degree of geometric complication, but with the tool like automatic mesh generator relevance and sizing of elements it becomes easier. Automatic meshing has limitations as regards mesh quality & solution accuracy because Automatic brick element (hex) mashers are limited in function, but these are steadily improving. Any mesh is usually applied to the model by simply selecting the mesh command on the pre-processor list of the GUI expansion, friction, thermal conductivity, damping effect, specific heat etc.) Will have to be defined. In addition element properties may need to be set. If 2D elements are being used, the thickness property is required. Special elements require properties specific to the element types like mass, contact, spring, gap, coupling, damper etc. to be defined for their use.

4.1.5 Apply Loads

Some sort of load is generally connected to the examination model. The stacking may be as a point load, a weight or a dislodging in an anxiety (relocation) investigation, a temperature or a heat flux in a thermal examination & a liquid weight or speed in a fluid examination. The loads may be connected to a point, an edge, a surface or an even a complete body. The loads ought to be in the same units as the model geometry & material properties indicated. In the instances of modular (vibration) & clasping examinations, a load does not need to be determined for the investigation to run.

4.1.6 Applying Boundary Conditions

On the off chance that you apply a load to the model, then so as to stop it quickening endlessly through the PC's virtual ether (scientifically known as a zero turn), no less than one requirement or limit condition must be connected. Auxiliary limit conditions are more often than not as zero relocations, thermal BCs (boundary conditions) are generally indicated temperatures, fluid BCs are typically determined weights. A limit condition may be determined to act in all headings (x, y, z), or in specific bearings just. They can be put on hubs, key focuses, and zones or on lines. BC's on lines can be as symmetric or hostile to symmetric sort limit conditions, one permitting in plane pivots and out of plane interpretations, the other permitting in plane interpretations and out of plane turns for a given line. The uses of right limit conditions are discriminating to the precise arrangement of the outline issue. No less than one limit condition must be connected to each model, even modular & clasping examinations with no loads connected. See the 'Propelled Boundary Conditions' segment for clarifications on more propelled limit condition sorts.

4.1.7 Solution

Thankfully, this part is completely programmed. The FE solver can be consistently isolated into three primary parts, the pre-processor, the mathematical engine, & the post-processor. The pre-processor peruses in the model made by the pre-processor and defines the scientific representation of the model. All parameters characterized in the pre-processing stage are utilized to do this, so in the event that you forgot something, odds are the pre-processor will gripe & cross out the call to the mathematical engine. On the off chance that the model is amend the solver continues to shape the component solidness network for the issue & calls the mathematical engine which computes the outcome (dislodging, temperatures, weights, and so on.) The outcomes are come back to the solver & the post-solver is utilized to ascertain strains, hassles, heat fluxes, speeds, and so forth for every hub inside the part or continuum. Every one of these outcomes are sent to an outcome record, which may be perused by the post-processor.

4.1.8 Post-Processor

Thankfully, this part is completely programmed. The FE solver can be consistently isolated into three primary parts, the presolver, the scientific motor, & the post-solver. The presolver peruses in the model made by the pre-processor and defines the scientific representation of the model. All parameters characterized in the pre-processing stage are utilized to do this, so in the event that you forgot something, odds are the presolver will gripe & cross out the call to the scientific motor. On the off chance that the model is amend the solver continues to shape the component solidness network for the issue & calls the scientific motor which computes the outcome (dislodging, temperatures, weights, and so on.) The outcomes are come back to the solver & the post-solver is utilized to ascertain strains, hassles, heat fluxes, speeds, and so forth for every hub inside the part or continuum. Every one of these outcomes are sent to an outcome record, which may be perused by the post-processor.

4.2 Material used for the analysis:

4.2.1 Cast iron:

This is a good option for a high volume production. Chilled cast iron camshaft have greater value of wear resistance because the lobes of the cam have been chilled, generally makes them harder. Before chilled iron casting some materials also added to the cast iron to make the material more suitable for the application.

4.2.2 Structural steel:

Whenever a high performance camshaft is required it is being made by billet steel. This is very low volume production process and very time consuming. The method is very expensive but the finishing that is obtained is far better than other process. Therefore we are going to use three different material

4.2.3 EN 8D steel

Compositions of elements used in EN8 D –

Table 1: Chemical composition of EN8D.

Carbon	0.36-0.44%
Silicon:	0.10-0.40%
Manganese	0.60-1.00%
Sulphur:	0.050 Max
Phosphorus	0.050 Max

EN8D is the medium carbon and medium tensile steel used mainly for axels spindles, studs, automotive and general engineering products or components. Suitable for heat treatment if extra strength is required

It is medium high carbon steel that can be strengthen by heat treatment after forming machinability and weldability are fine and fair.

Typical uses includes machine parts U bolts, concrete re-enforcing rods, forging and non-critical spring.

Mechanical properties:

Table 2: Mechanical properties of EN8D

Properties	Metric values
Hardness, brinell	300
Hardness, Rockwell	30
Tensile strength, ultimate	965-1030 Mpa
Tensile strength, yield	827-862 Mpa
Compressive strength	862 Mpa
Poisson’s ratio	.27-.30
Elastic modulus	190-210Gpa

4.2.4 EN 28 steel:

Composition of elements used in EN 28-

Table 3: Chemical composition of EN28

Carbon	0.25%
Silicon:	0.15%
Manganese	0.52%,
Sulphur:	0.024%,
Phosphorus	0.010%
Chromium	1.14%
Molybdenum	0.65%
Vanadium	0.16%
Nickel	3.33%

4.2.5 EN 24 steel:

Composition of elements used in EN 24 –

Table 4: Chemical composition of EN24

Carbon	.36/.44%
Silicon:	.10/.35%
Manganese	.45/.70%,
Sulphur:	.040%,
Phosphorus	.035%
Nickel	1.30/1.70%
Chromium	1.00/1.40 %
Molybdenum	.20/.30%

EN24 is a very popular of through hardening alloy steel, it is most suitable for the manufacturing of the parts such as heavy duty axles and shafts, gears, bolts and studs. EN24 can be further be surface hardened typically to 58 to 60 HRC by induction or nitride processes, producing components which enhanced wear resistance. EN24 is capable of retaining good impact value at low temperatures.

For the model design purpose here we have used the Solidworks software which is a very reputed 3D CAD design software the analysis and simulation can also be done on the same software but for specific results and accuracy we have used ANSYS software

4.3 WORK PLAN WITH TIME

Month Activity	Sep.	Oct	Nov	Dec	Jan	Feb	Mar.
Objective	▨						
Literature Review	▨	▨	▨				
Design			▨		▨	▨	
Experimental design/analysis			▨	▨	▨	▨	
Results and discussion					▨	▨	
Report writing			▨	▨	▨	▨	▨

Table 5: work plane with estimated time

CHAPTER -5

5 RESULTS AND DISCUSSION

5.1 TOTAL DEFORMATION IN CAMSHAFT OF DIFFERENT MATERIALS

Camshaft is the rotating component that bears the critical loads. The calculation of the exact load is very important for the part than the other rotating parts of the engine. This paper provides the guidelines to deal with such situations hence the objective is to design the camshaft analytically and analyse the frequency and vibrations in modal analysis and the total deformation statically.

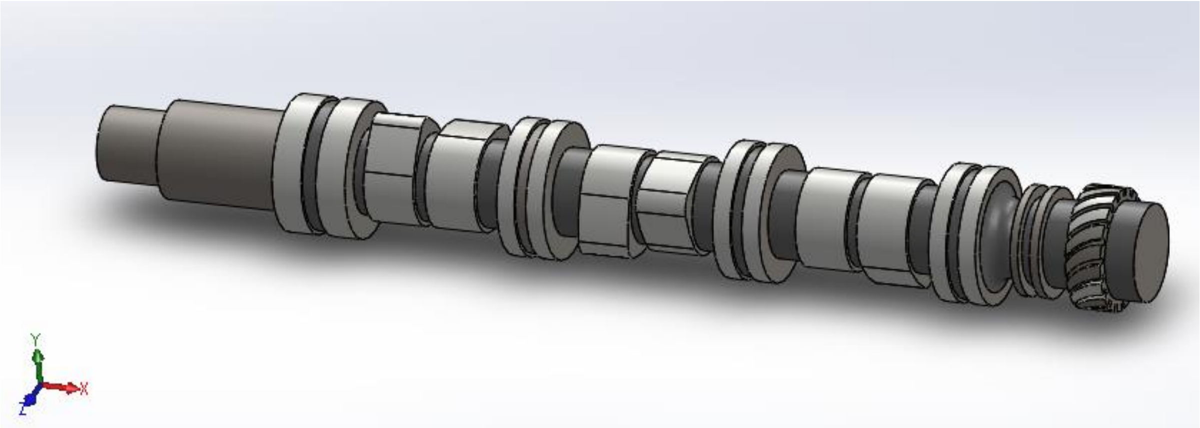


Figure 5: showing the CAD model of camshaft

Units used:

Unit System:	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle:	Degrees

5.1.1 Loading conditions:

5.1.1.1 Calculation of loads on camshaft:

Engine specifications:

Table 6: Engine specification for loading

Power	27.6KW at 5000 RPM
Torque	59Nm at 2500 RPM
Cylinder volume	796CC
Stroke	72mm
Bore	66.5mm
C.R (compression ratio)	9:2
Inlet valve opens	10° BTDC
Firing order	1-3-2

An engine of 800 cc was tested and the values those are given in the above table was obtained it generated 27.6 KW of power when it was at full throttle i.e at 5000rpm. The total torque on the shaft was 59Nm when crank was rotating at a speed of 2500 rpm, bore diameter measured was 66.5mm and the firing order given was 1-3-2 or 1-2-3.

Camshaft specifications:

Table 7: Camshaft specifications.

Cam width	18mm
Camshaft diameter	28.6mm
Journal diameter	50mm
Cam height	41.3mm
Total lift of cam	7.65mm

The camshaft that was being tested was having a base diameter of 28.66mm and having 6 cams on it with 18mm width each. The journal bearing those were on the camshaft were of 50mm diameter. The cam lift calculated was 7.65mm but the cam that we have designed have the lift of 11mm.

Mass of valve and accessories:

Table 8: Valve and accessories specifications.

Mass of valve	100gm
Valve head diameter	18.6mm
Valve head diameter	61.1 mm
Spring mass	28gm

5.1.1.2 Force acting on camshaft:

1.Force exerted by valve-

$F_{e\text{-}v}$ = valve inertia force * mass of valve

= -191.861*0.100

= -19.1861 N

2.Spring force= $F_{e\text{-}v} = H_v * K$

$H_v = 0$ (valve lift)

K = 18 N/mm

Total force = 0 N

3. Volume calculation:

$X_p = r\,(1 - \cos\theta + n - \sqrt{}\,(n^2 - \sin 2\theta))$

Here n= 3,

Clearance ratio = 9:2

$R_c = (V_s + V_c) / V_c$

$V_s = (\pi/4) * d^2 * L$

$= (\pi/4)\,(66.5*10^{-3})^2 * 72*10^{-3}$

$V_s = 2.49945*10^{-4} m^3$

$V_c = V_s + V_c / R_c$

$V_c = 6.857*10^{-5}\ m^3$

Total volume:

$V_t = V_s + V_c$

$= 3.18515*10^{-4} m^3$

4. Gas force:

F_g =Valve head area* gas pressure

$= (\pi/4) * d_p * P'$

$= 271.5*10^{-6} m^2 * .6065$ Mpa

= 164.52 N

Force on camshaft:

= 164.52*(rocker arm ratio)

= 164.52*(39.3/36.3)

=178.11 N

5. Deflection in shaft-

$y = 0.8 * F_{max} * a^2 * b^2 / [E * L*(dc^4 - \delta c^4)]$……………………………………….. [1]

y=.0024mm

6.Bending stress:

$\sigma_b = [M_{bmax} / W_b] = [F_{max} * b * a * 32] / [\pi * dc^3 * (1-(\delta c^4 / dc^4)) * L]$……. [1]

σ_b= 1.399Mpa

5.1.2 MODEL

5.1.2.1 Geometry:

Table 9: Details of the geometry used for FE analysis

Object Name	Camshaft
State	Fully Defined
Bounding Box	
Length X	357. mm
Length Y	44.5 mm
Length Z	44.5 mm
Properties	
Volume	3.3025e+005 mm^3
Mass	2.5925e-003 kg
Statistics	
Nodes	28701
Elements	17207

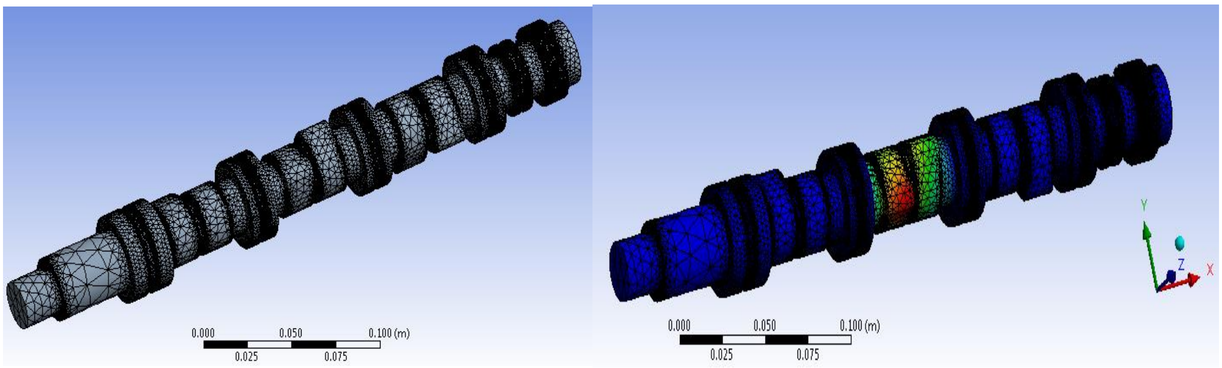


Figure 6 : Showing the meshed wireframe and deformed wireframe of camshaft.

5.1.3 For EN8D:

EN8 D is the medium carbon and medium tensile steel used mainly for axels spindles, studs, automotive and general engineering products or components. Suitable for heat treatment if extra strength is required

It is medium high carbon steel that can be strengthen by heat treatment after forming machinability and weld ability are fine and fair.

Typical uses includes machine parts U bolts, concrete re-enforcing rods, forging and non-critical spring. In camshaft we have used the same material and calculated these results:

Table 10: Showing the bounding box and the geometric properties for the model EN8D.

Material	
Assignment	EN8 D
Bounding Box	
Length X	357. mm
Length Y	44.5 mm
Length Z	44.5 mm
Properties	
Volume	3.3025e+005 mm³
Mass	2.5846 kg
Centroid X	182.49 mm
Centroid Y	-5.2718e-016 mm
Centroid Z	1.0523e-015 mm
Moment of Inertia Ip1	0.43095 kg·mm²
Moment of Inertia Ip2	25.812 kg·mm²
Moment of Inertia Ip3	25.812 kg·mm²
Statistics	
Nodes	769368
Elements	498211

5.1.4 For Cast iron:

Cast iron is iron or a ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through. Grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks. It is a very good vibration absorber, but since it shows the brittle nature in the structures its strength is not so high for the applications like camshafts.

Table 11: Showing the bounding box and the geometric properties for the model cast iron

Material	
Assignment	Cast Iron
Bounding Box	
Length X	0.357 m
Length Y	4.45e-002 m

Length Z	4.45e-002 m
Properties	
Volume	3.2925e-004 m^3
Mass	2.3706 kg
Centroid X	0.18204 m
Centroid Y	-1.551e-007 m
Centroid Z	-3.5636e-008 m
Moment of Inertia Ip1	3.9288e-004 kg·m^2
Moment of Inertia Ip2	2.3502e-002 kg·m^2
Moment of Inertia Ip3	2.3502e-002 kg·m^2
Statistics	
Nodes	769368
Elements	498211

5.1.5 For EN 24

EN24 is a very popular of through hardening alloy steel, it is most suitable for the manufacturing of the parts such as heavy duty axles and shafts, gears, bolts and studs. EN24 can be further be surface hardened typically to 58 to 60 HRC by induction or nitride processes, producing components which enhanced wear resistance. EN24 is capable of retaining good impact value at low temperatures.

Table 12: Showing the bounding box and the geometric properties for the model EN24

Material	
Assignment	EN24
Bounding Box	
Length X	357. mm
Length Y	44.5 mm
Length Z	44.5 mm
Properties	
Volume	3.3025e+005 mm^3
Mass	2.69 kg
Centroid X	182.49 mm
Centroid Y	-5.2718e-016 mm
Centroid Z	1.0523e-015 mm
Moment of Inertia Ip1	0.43095 kg·mm^2
Moment of Inertia Ip2	25.812 kg·mm^2
Moment of Inertia Ip3	25.812 kg·mm^2
Statistics	
Nodes	769368

Elements	498211

5.1.6 For structural steel:

Table 13: Showing the bounding box and the geometric properties for the model structural steel.

Material	
Assignment	Structural steel
Bounding Box	
Length X	357. mm
Length Y	44.5 mm
Length Z	44.5 mm
Properties	
Volume	3.3025e+005 mm³
Mass	2.5846 kg
Centroid X	182.49 mm
Centroid Y	-5.2718e-016 mm
Centroid Z	1.0523e-015 mm
Moment of Inertia Ip1	0.43095 kg·mm²
Moment of Inertia Ip2	25.812 kg·mm²
Moment of Inertia Ip3	25.812 kg·mm²
Statistics	
Nodes	769368
Elements	498211

5.2 STATIC STRUCTURAL ANALYSIS

In static structural analysis the load applied is 178.11N and the corresponding deformation has been calculated by the software the total deformation for the various materials is-

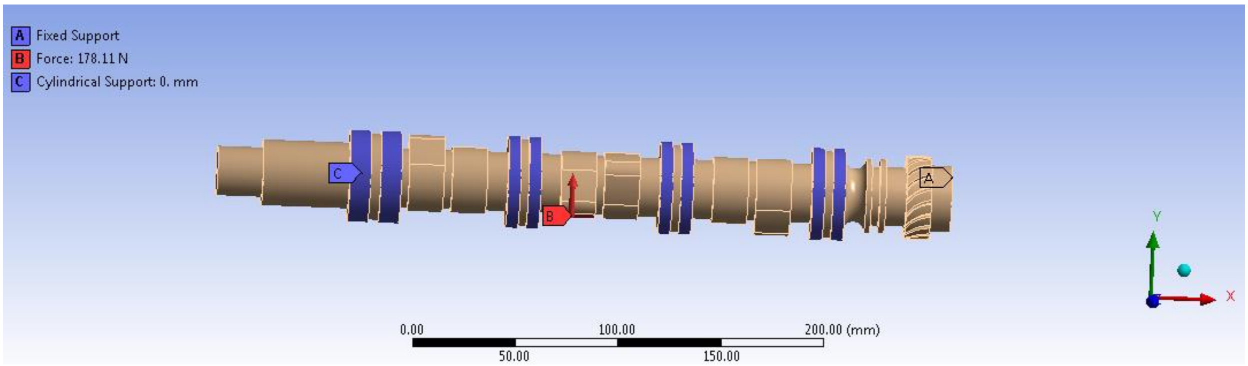


Figure 7: showing the boundary conditions for the analysis

5.3 RESULTS

Table 14 : Results - Total deformation, equivalent (von mises) stress and strain.

Materials	Equivalent stress (von mises) Mpa	Equivalent strain (von mises)	Total deformation
EN8D	2.32×10^{-6} - .980	1.86×10^{-11} – 5.02×10^{-6}	1.6×10^{-5}mm -1.49×10^{-4}mm
EN24	1.86×10^{-6}- 0.98	1.19×10^{-11} –4.04×10^{-6}	1.32×10^{-5}mm -1.19×10^{-4}mm
SS (structural steel)	2.32×10^{-6}-0.98	1.95×10^{-11}-5.27×10^{-6}	1.74×10^{-5}mm-1.66×10^{-4}mm
Cast iron	1.98×10^{-6}- .97	3.04×10^{-11}-9.64×10^{-6}	3.15×10^{-5}mm-2.80×10^{-4}mm

The equivalent stress and strain in various material has been calculated with total deformation for each material and the comparison has been done for the best material. We are focussing here the performance of the engine so for three materials the value of maximum stress has come out to be same i.e. .98Mpa and the fourth one is also a little offset by .01Mpa i.e. cast iron now to evaluate a material on the bases of stress is very difficult so we talk about another parameter i.e. strain .The strain value in EN8D and EN24 are the lowest one and at the same time deformation in both the material are very less. But since the weight of EN24 is very high than the weight of EN8D it can’t compensate the factor of performance of engine over weight. So a little compromization with deformation can be done to gain the total performance of the engine.

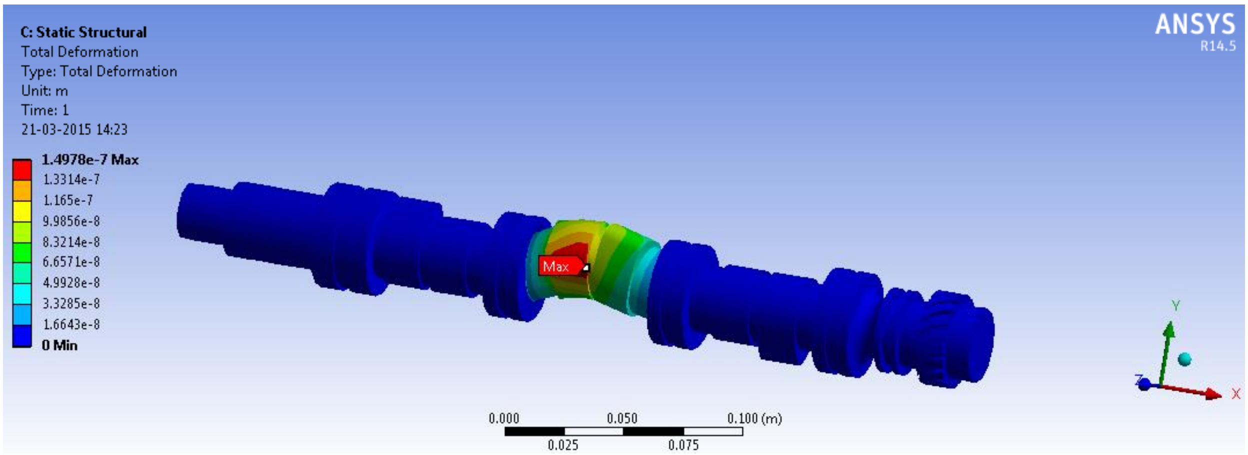


Figure 8: Showing the total deformation of camshaft

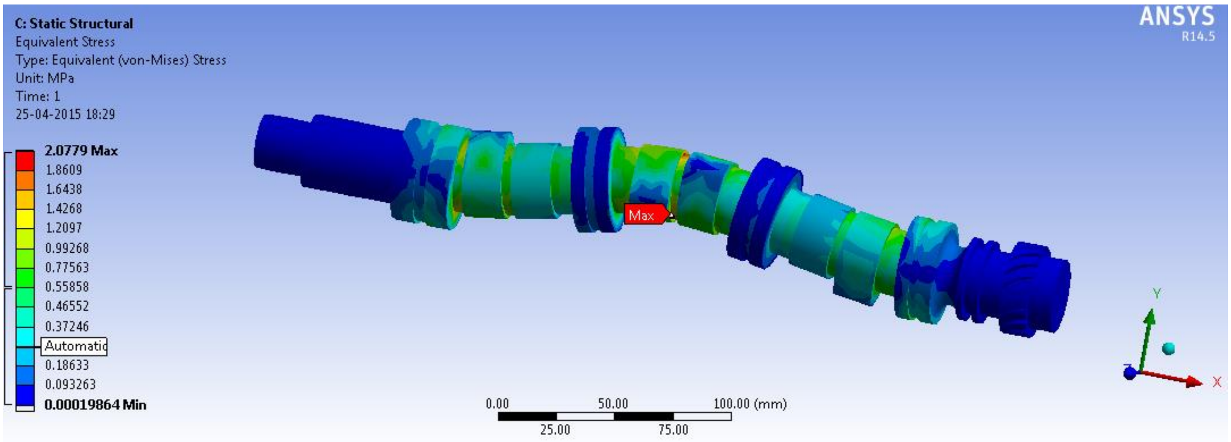


Figure 9: Equivalent stress (Von- mises) of camshaft

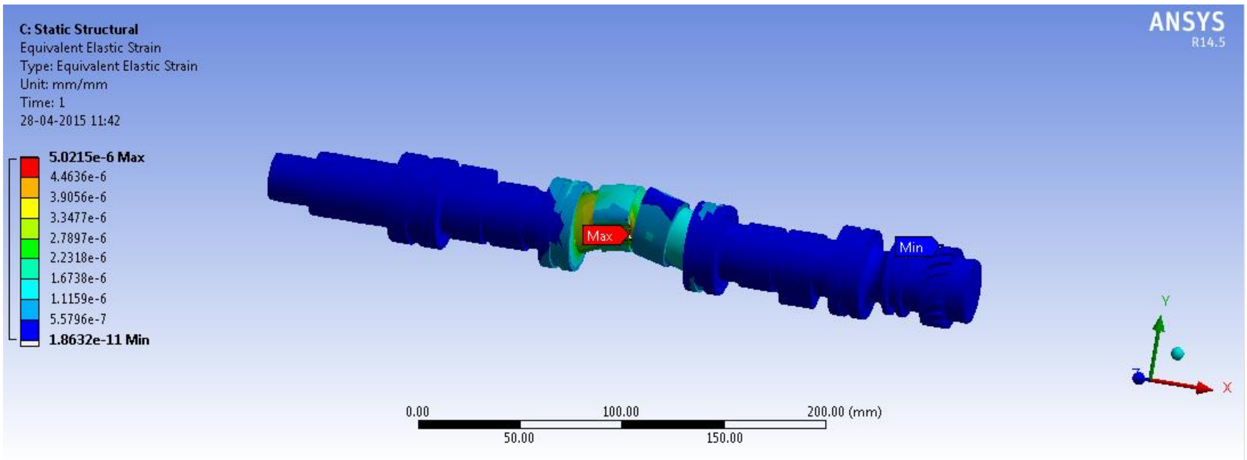


Figure 10: Equivalent strain (Von mises) of the camshaft

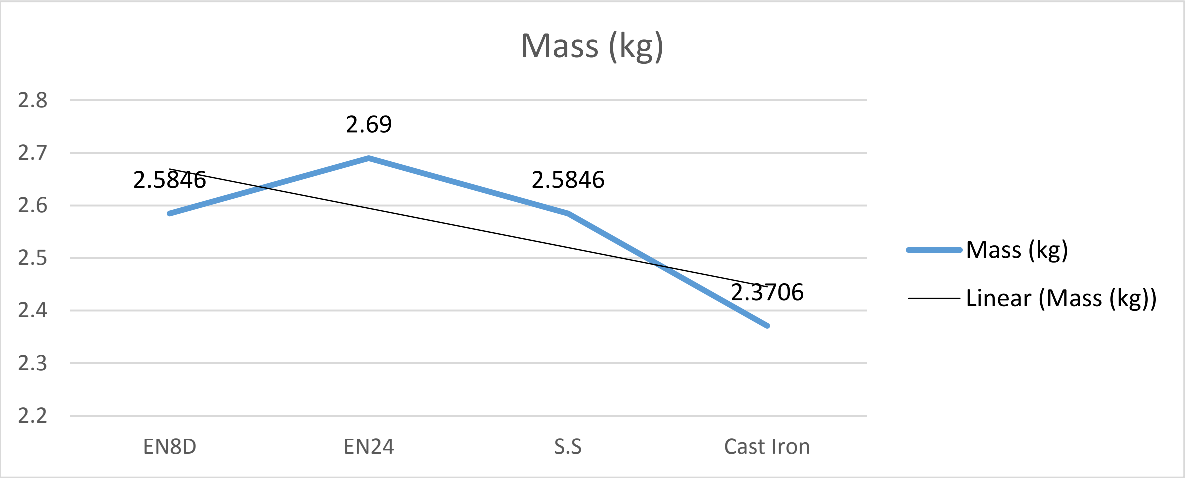


Figure 11 : Graph showing comparison between mass of different camshafts of different materials

5.4 ANALYSIS OF CAMSHAFT IN ROTATING CONDITIONS

5.4.1 Boundary conditions:

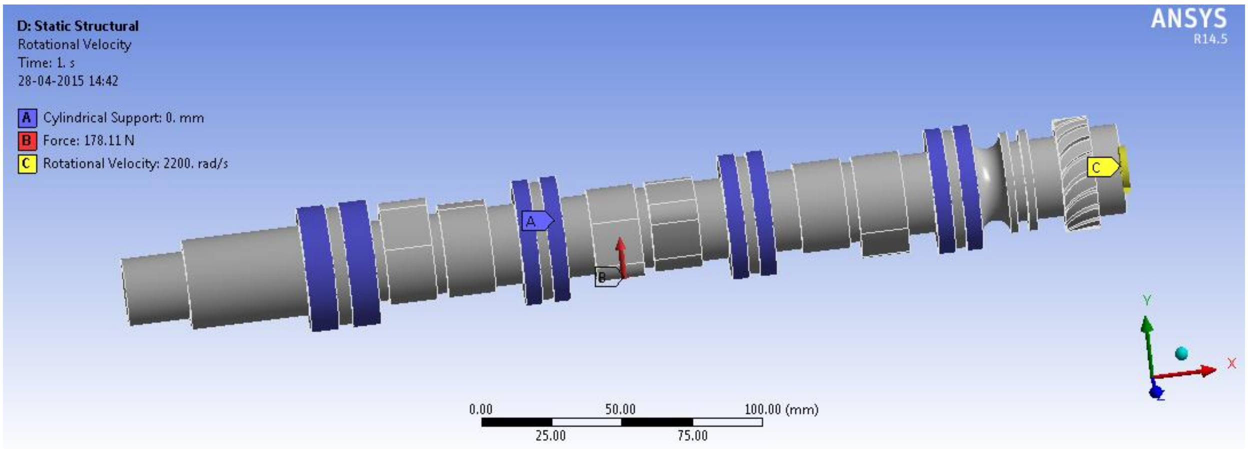


Figure 12: boundary conditions for the camshaft in rotating conditions.

For EN8D:

Table 15: Showing the results for EN8D material.

	Total deformation	Equivalent stress	Equivalent strain
Minimum	8.20×10^{-5} mm	0.28537 MPa	1.4198e-006 mm/mm
Maximum	7.3881×10^{-4} mm	7.5739 MPa	3.6071e-005 mm/mm

For EN8D the total deformation (maximum and minimum) has been calculated using the ANSYS workbench software. Maximum value of deformation is .0007388mm with 7.573Mpa stress value.

For EN24:

Table 16: Showing the results for EN24 material.

	Total deformation	Equivalent stress	Equivalent strain
Minimum	6.99×10^{-5} mm	0.32777 MPa	1.3095e-006 mm/mm
Maximum	6.2958×10^{-4} mm	8.1487 MPa	3.1345e-005 mm/mm

For EN24 the value of total deformation is less than the value that has obtained from EN8D but the value of stress in the camshaft is greater than EN8D. Therefore we have calculated the factor of safety for both the material which came out to be higher in case of EN8D because of low value of stress in rotation. It means this material can give a long life in operating conditions, in comparison to EN24.

For Structural steel:

Table 17: Showing the results for S.S material.

	Total deformation	Equivalent stress	Equivalent strain
Minimum	8.61×10^{-5} mm	0.28537 MPa	1.4908e-006 mm/mm
Maximum	7.7575×10^{-4}mm	7.5739 MPa	3.7874e-005 mm/mm

For structural steel we have seen that the total deformation is so large so that it can't be use for the operation. Although it has lower value of stress than EN24.

For cast iron:

Table 18: Showing the results for Cast iron.

	Total deformation	Equivalent stress	Equivalent strain
Minimum	1.459×10^{-4} mm	0.27909 MPa	2.6406e-006 mm/mm
Maximum	1.3135×10^{-3} mm	7.103 MPa	6.458e-005 mm/mm

Cast iron has shown some really good results for the analysis and there for it has chosen for the vibration analysis of camshaft because it has the tendency to absorb the vibration but while rotation it showed some really high value of deformation for the minimum and the maximum value of deformation that's why it is not suitable material for application.

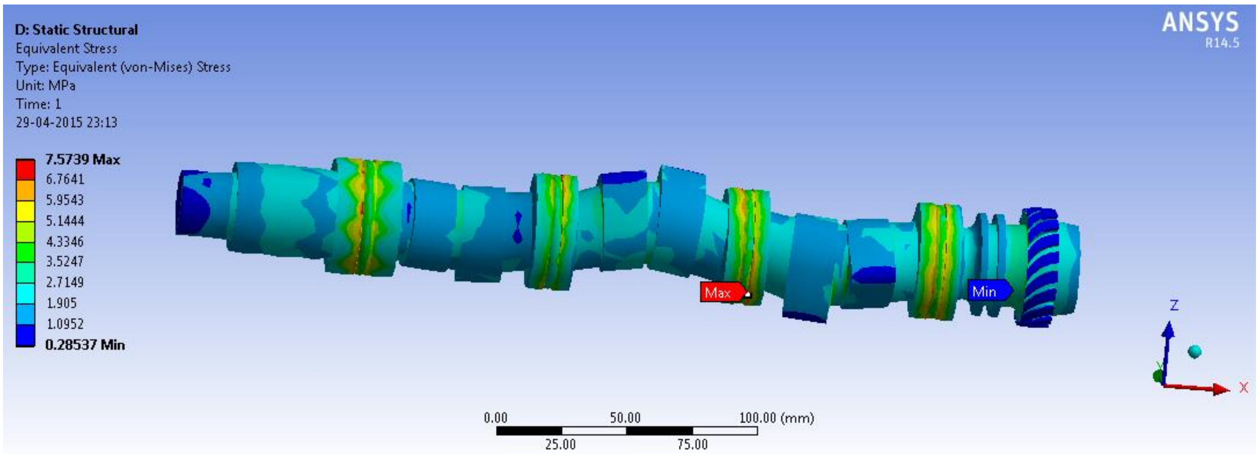


Figure 13: Showing the equivalent (Von mises) stress in camshaft while rotating.

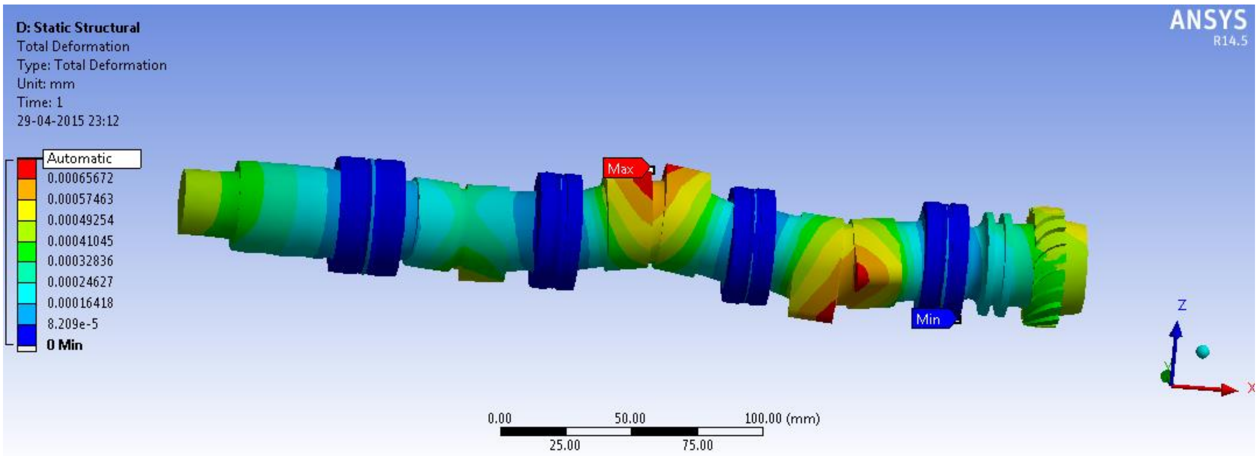


Figure 14: Showing the total deformation in the camshaft while rotation in loading condition.

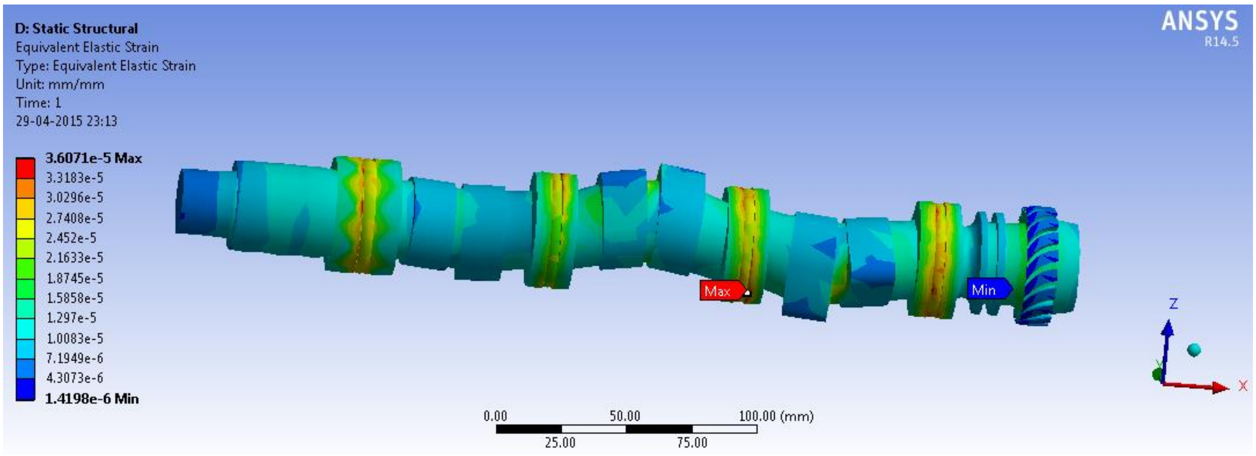


Figure 15: Showing the equivalent (Von mises) strain in camshaft while rotation.

The static structural model analysis of the camshaft is done in the ANSYS software which is a very reputed and relevant software for the FE analysis. This analysis shows that if the material of the camshaft improves the deformation in the shaft reduces to the certain levels here we have compared various material for the camshaft. From all those material EN8D steel has shown the best results and best suitable material for the camshaft. Because if we are going for the reduction in weight the deformation increases and if we are choosing the minimum deformation the material mass is increasing so EN8D has shown the results that have acceptable weight and deformation.

5.5 MODAL ANALYSIS OF CAMSHAFT:

Modal analysis of the camshaft means the free vibration analysis of camshaft in which the natural frequency of vibrations are calculated at the no loads conditions. With the help of the software we have calculated the frequencies for the camshaft for different materials and compared them with each other. The validation of the results are done by the simple vibration analysis of a mild steel rod which was available as an experimental setup in lab the results were validated with the same boundary conditions as there present in the engine head or during the free rotation of the shaft.

5.5.1 EN24:

Following are the natural frequencies at different modes for the material EN24.

Table 19 : Showing the natural frequencies and deformation with different modes of EN24 camshaft

Mode	Frequency [Hz]	Deformation
1.	17505	64.724 mm
2.	17605	59.219 mm
3.	18131	63.392 mm
4.	18200	59.479 mm
5.	20268	97.121 mm
6.	20493	79.219 mm

5.5.2 **END8:**

For EN8D following are the natural frequencies obtained with respected deformations.

Table 20: Showing the natural frequencies and deformation with different modes of EN8D camshaft

Mode	Frequency [Hz]	Deformation
1.	16036	67.055 mm
2.	16137	61.155 mm
3.	16645	65.871 mm
4.	16715	61.475 mm
5.	18593	100.89 mm
6.	18814	81. mm

5.5.3 Structural steel:

Following are the natural frequencies obtained for the structural steel camshaft.

Mode	Frequency [Hz]	Deformation
1.	15650	67.055 mm
2.	15749	61.155 mm
3.	16244	65.871 mm
4.	16312	61.475 mm
5.	18145	100.89 mm
6.	18360	81. mm

Table 21: Showing the natural frequencies and deformation with different modes of SS camshaft

5.5.4 Cast iron:

Following is the table that is obtained for the natural frequencies and the deformation at different mode shape for cast iron camshaft.

Table 22: Showing the natural frequencies and deformation with different modes of cast iron camshaft

Mode	Frequency [Hz]	Deformation
1.	12125	69.292 mm
2.	12196	63.329 mm
3.	12567	67.929 mm
4.	12616	63.62 mm
5.	14044	104.07 mm
6.	14204	86.32 mm

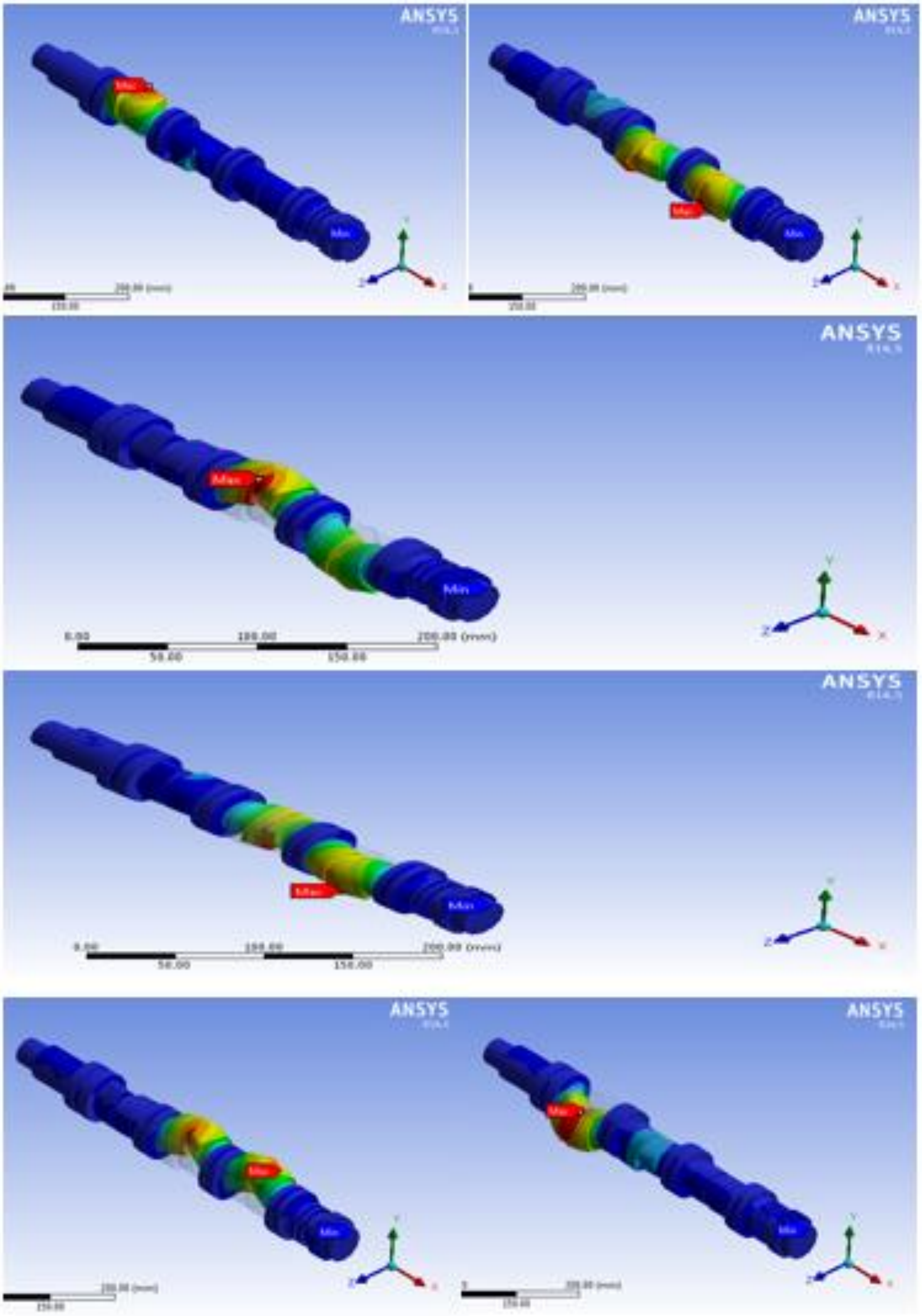


Figure 16: showing 6 mode shapes of camshaft with deformations

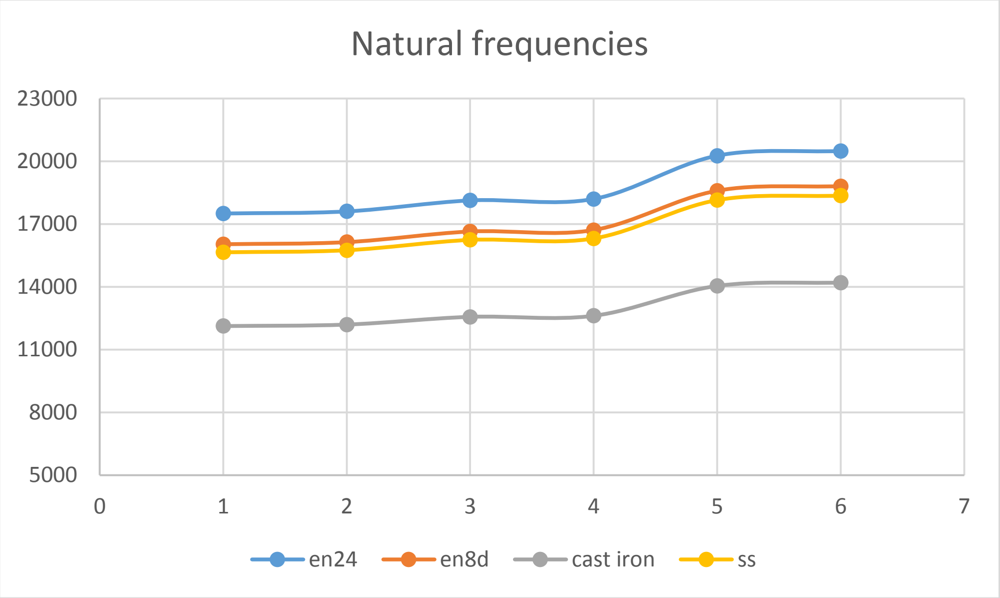


Figure 17: Graph showing the comparison between the natural frequencies of different material camshaft

5.6 ANALYSIS PROCEDURE:

First step is to prepare the 3D cad model in any of the 3D cad software here we have used the solidworks for this purpose. Solid modelling is done with exact dimension of a 3 cylinder SI engine camshaft. Then the solid model is being imported to the ANSYS software using the given neutral file formats. Then it is opened in the workbench to analyse the analysis procedure takes 4 steps. But first we have analysed the masses and the deformation in the camshafts with different materials.

After analysing the various material we can see the material which is having the lowest mass having the highest value of deformation and the material that have the lowest deformation have the highest mass. So if the material is to be choose from the given data it is EN8D which is having the lower weight value and the lower deformation in the operating conditions. For the vibration analysis the MODAL ANALYSIS in ANSYS Workbench. This process includes the following four steps.

Pre procedure: this step specifies the 2D CAD geometry of the model in the ANSYS workbench environment and all the dimensioning of the model is converted according to the module. Most preferably we should take the same dimensions in the analysis as they were taken in the cad modelling geometry. Else the values of the results will be much distorted and off the limits sometimes.

Meshing: Meshing is the process of dividing the model in the small and discreet elements called the meshing elements, there are various type of meshing elements present in the software like brick elements, pyramidal, spherical, cubical triangular etc. meshing is done because it is so easy to calculate the problem for a small element than a bulk material therefore it is said that finer the mesh better will be the results. For the current project we have employed the mashing according to the curves and proximity.

Applying loads: this step is so important for the analysis because it defines the boundary for the results of the problem. And the scope of results are defined in this step. All the loads on the models and the boundary conditions should be applied at the exact locations for the exact solutions to the problem.

Post process: This step specifies the results to the problem, first the postprocessor reads the problem and the boundary conditions then it generates the mathematical model of the problem then the equation to the solutions are formed and the results are calculated. Then the results are applied to the geometry to show the final shape of the geometry if it is feasible then it would generate the final results but if it is not possible then it returns back to the pre-processor to generate the mathematical model again and run the solution again until the desired solution is obtained.

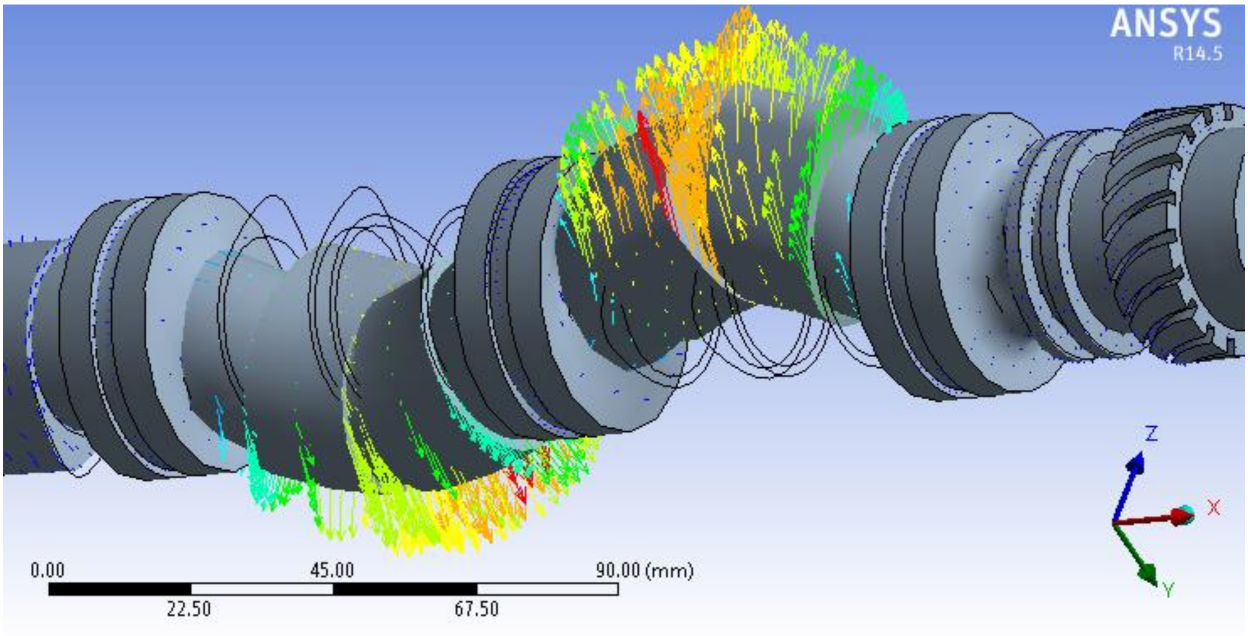


Figure 18: Final deformed shape of camshaft.

5.7 VALIDATION

5.7.1 Problem description:

To study the vibration and the natural frequency of model, is the main problem of this study. One can only determine the deformation by calculating the force generated by the cylinder but no one can determine the exact same conditions of the loading and exact environment in which the camshaft is operating. There is no direct method to calculate the exact loading and boundary conditions. Therefore there will be a slight deflection between the both values. For the solution here we have used the ANSYS software for analytical solution of the problem and the theoretical solution is being done by own studies.

5.7.2 Analysis of the natural frequency of a shaft (no load condition):

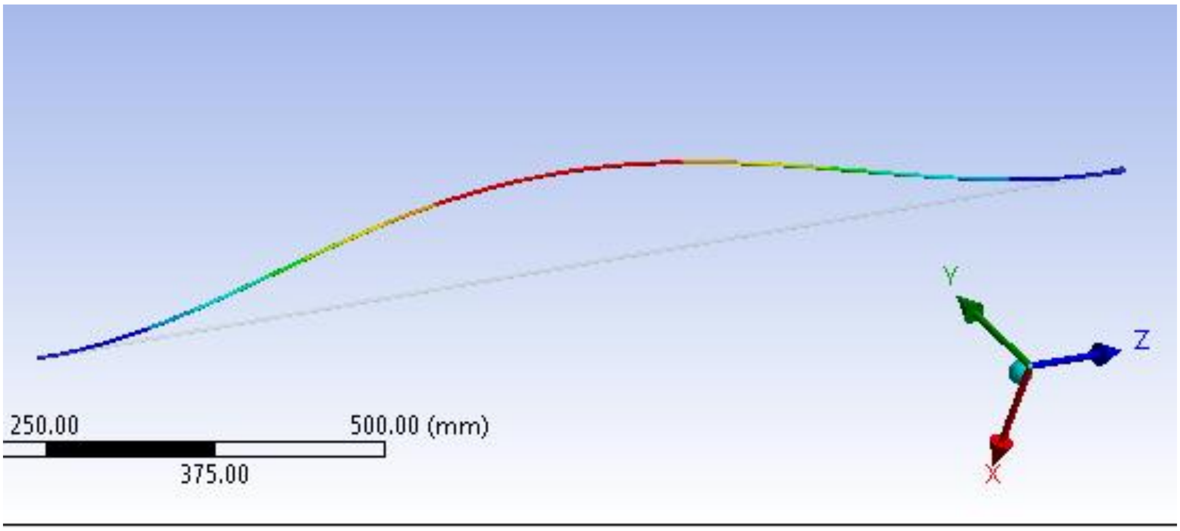


Figure 19: Showing the cad model of shaft

5.7.2.1 Shaft specifications:

Table 23: Specifications of shaft

Elasticity of shaft	$189x\ 10^9$ N/m
Length of shaft	106.5 Cm
Diameter	.3 Cm
Mass	80 gm
Gravity	9.8 m/sec^2

The shaft which has been used for the experimental analysis was of mild steel and having a diameter of 3mmwith a total length of 1.05m. The weight of shaft has given in table 24.

5.7.2.2 Boundary conditions for shaft:

Table 24: Boundary conditions applied

Speed when both ends are fixed	Speed when simply supported	Speed when one end is freed
760 rpm	415rpm	610rpm

Boundary conditions for the shaft can be specify in three modes first when it's both ends are fixed second when it's simply supported and third when both the ends are freed. The rotational speed was given to shaft in each case and the frequency was calculated for respective cases.

$I = \pi/64 \times d^4$

7. Moment of inertia of cylinder

$= \pi/64\ (3\times10^{-3})^4$

$= 3.96\times10^{-12} m^4$

W= weight per unit length

$= 0.080\times9.8/1.065$

$=7.36$ N/m

8.Natural Frequency (both ends fixed):

$F_n= [\pi/2(n+1/2)\ \sqrt{}\ (gEI)] / WL^4$

For n=1

$F_n=10.152$ Hz

For n=2

$F_n=28.2$ Hz

For n=3

$F_n= 55.27$ Hz

9.Natural frequency (both ends are supported):

$F_n= [\pi/2(n^2)\ \sqrt{}\ (gEI)] / WL^4$

For n=1

$F_n= 4.512$ Hz

For n=2

F_n= 18.078 Hz

For n=3

F_n= 40.601 Hz

10. Natural frequency (both ends are freed):

F_n= $[\pi/2(n -1/2) \sqrt{(gEI)}] / WL^4$

For n=1

F_n= 1.128 Hz

For n=2

F_n= 10.152 Hz

For n=3

F_n= 98.2 Hz

5.8 ANALYTICAL SOLUTION:

Analytical solution with boundary conditions same as the camshaft.

5.8.1 Boundary conditions:

Object Name	Shaft
State	Meshed
Definition	
Stiffness Behaviour	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	MS
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	5. mm
Length Y	5. mm
Length Z	1085. mm
Properties	

Volume	7773.5 mm^3
Mass	6.1022e-002 kg
Centroid X	7.1047e-017 mm
Centroid Y	2.0288e-017 mm
Centroid Z	552.68 mm
Moment of Inertia Ip1	6104.8 kg·mm^2
Moment of Inertia Ip2	6104.8 kg·mm^2
Moment of Inertia Ip3	7.0876e-002 kg·mm^2
Statistics	
Nodes	16881
Elements	7955

Table 25: Boundary conditions of the shaft.

5.8.2 Results:

Table 26: Results showing the total deformation on various frequencies

	Results					
Maximum deformation	653.8 mm	653.51 mm	621.47 mm	621.4 mm	622.97 mm	622.83 mm
Frequency	11.59 Hz	11.5 Hz	31.948 Hz	31.953 Hz	62.642 Hz	62.647 Hz

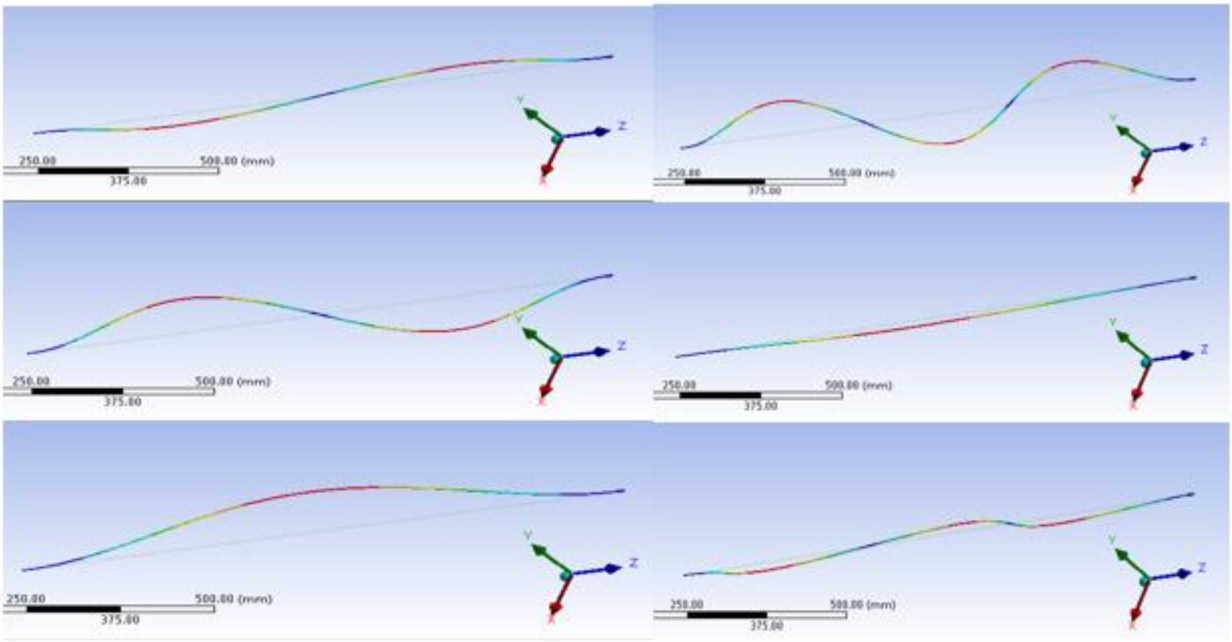


Figure 20: Mode shapes of shaft.

5.8.3 Conclusion:

Results shows that the natural frequency for the mild steel shaft that is calculated theoretically are matched with a slight margin of offset from natural frequencies those are being calculated by the software ANSYS. Therefore the same boundary conditions would also be applicable for the camshaft we are analysing here. Hence the calculations are validated both analytically and theoretically.

Values of frequencies from experiments (Hz)	Values of frequencies from the software (ANSYS) in (Hz)
10.152	11.594
	11.596
28.2	31.948
	31.953
55.27	62.642
	62.647

Table 27: Comparison of theoretical and analytical values.

CHAPTER- 6

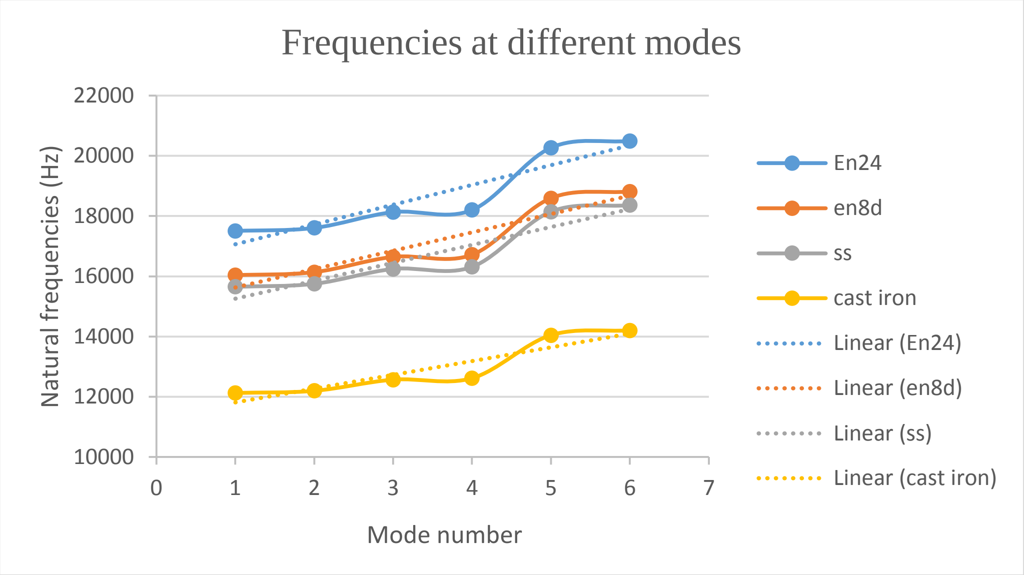
6 CONCLUSION

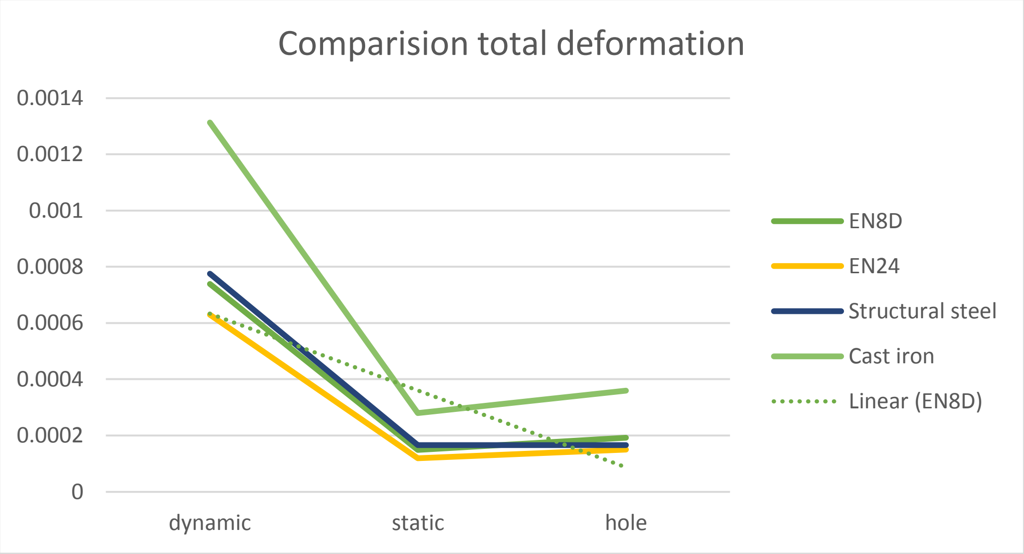
The FE analysis of camshaft has been done and we have found the material that is appropriate for the fabrication of the camshaft it may be cost effective and easily available in the market here we have seen the various parameters on which the manufacturing and the application of the components relies but sometimes when we talk about the performance we need the least disturbed element or the component in the system then according to the performance point of view the camshaft of cast iron is a suitable option for us but it also have some major disadvantages it is having the high weight and larger deformation with time but very low value of vibrations as we all know cast iron is the best vibration absorber element but it doesn’t have that suitable strength which is needed for application. Now if we see the weight with performance the structural steel and EN24 steel are the good option for the manufacturers but if we see it from the mechanical point of view they doesn’t seem to have the good option while working conditions they shows very large deformation values at the resonance conditions. Now there is only one material that we are left with here i.e. EN8D. This material shows the good results rather the least deformation at the resonance frequencies and have light weight than structural steel and EN24. Have good torsional strength but higher than the cast iron if we have to choose a material among all these four elements one have to compromise between the performance and the weight of the component so we can conclude that the EN8D is the material which may be used to manufacturing of camshaft.

6.1 RESULTS

Table 28 : Comparison between total deformation and frequencies of different materials.

Materials	Total deformation (Dynamic, w=2200 rad/sec)	Total deformation (Static)	Frequency (Natural)
EN8D	7.3881×10^{-4} mm	1.49×10^{-4}mm	16036 Hz
EN24	6.2958×10^{-4} mm	1.19×10^{-4}mm	17505 Hz
Structural steel	7.7575×10^{-4}mm	1.66×10^{-4}mm	15650 Hz
Cast iron	1.3135×10^{-3}mm	2.80×10^{-4}mm	12125 Hz





From the Modal analysis and the static structural analysis we have seen that the EN8D material have shown the best results it has shown the least deformation in the corresponding frequencies and having the weight higher than the cast iron but lower than the structural steel and EN24. It has shown the least stress value of 2.32×10^{-6}Mpa and a least deformation of 1.6×10^{-5}mm to 1.49×10^{-4}mm. so EN8D is the suitable material for the camshaft manufacturing.

6.2 FUTURE SCOPE

With the help of this work the manufacturing processes for the camshaft can be decided. With this work one can do more analysis related to the camshaft. For another application the material selection for camshaft become easier for the manufacturer

6.3 RECOMMENDATIONS

If you want to get a higher performance with the light weight we can recommend the part with material EN8D to anyone but if one wants the lower vibration with compromization with weight one can choose the structural steel or cast iron camshaft.

CHAPTER -7

7 REFERENCES:

[1] S.-W. Chyuan, "Finite element simulation of a twin-cam 16-valve cylinder," *Finite Elements in Analysis and Design,* pp. 199-212, 2000.

[2] H. X. a. J. W. Zu, “Cam profile optimization for a new cam drive,” *Journal of Mechanical Science and Technology,* pp. 2592-2602, 2009.

[3] S. jhonson, design of machinery.

[4] V. A.S.Dhavale, “Study of Modeling and Fracture Analysis of Camshaft,” *International Journal of Engineering Research and Applications,* pp. 835-842, November- December 2012.

[5] P. D. M. S. H. G. J. S. B. Mahesh R. Mali, “Design Optimization of Cam & Follower Mechanism of an Internal Combustion Engine for Improving the Engine Efficiency,” *Modern Mechanical Engineering,* pp. 114-119, August 2012.

[6] D.-I. M. M. d. S. S. C. Philippe de Abreu Duque, “Contact pressure between cams and roller followers through Finite Elements Method (FEM) in assembled camshafts,” in *Virtual Powertrain Conferences,* Neumayer Tekfor Tech Center Brazil.

[7] K. K. D. Dave Marmik M., “Static Structure Analysis of Diesel Engine Camshaft,” *INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH,* pp. 208-209, May 2013.

[8] J. A. escobar, “stress and fatigue analysis of camshaft lobes,” virginia polytechnique institute of state university, virginia, November,1996.

[9] W. S. Ulf Andresen, “A SIMPLE CAM DESIGN PROCEDURE FOR AUTOMATIC SCREW,” *Symposium on Flexible Automation,* pp. 10-14, July,2002.

[10] R. B. L. K. Z. S. J. W. B. L. P. Folega, “Impact of the cam and follower cooperation and of lubrication on the cam wear,” *Archives of material science and engineering,* pp. 158-163, december 2012.

[11] T. C. P. R. V. Wanjari, “Design and Analysis of Camshaft by Changing Parameters which Causes Failure,” *International Journal of Science and Modern Engineering,* pp. 32-35, May 2013.

[12] L. F. C. A. a. W. B. Li Ping, “Fracture analysis of chilled cast iron,” *CHINA FOUNDRY,* pp. 104-108, february ,2009.

[13] K. M. Vivekanandan.P, “Modelling, Design and Finite Element Analysis of Cam Shaft,” *International Journal of Current Engineering and Technology,* pp. Vol.3, No.1, 1March 2013.

[14] P. sahoo, engineering tribology, delhi: PHI learning pvt. ltd., 2000.

[15] N. D. A. S. P. F. S.G.THORAT, “DESIGN & ANALYSIS OF CAMSHAFT,” in *IRF International*

Conference, Pune, 15th June-2014, Pune, India.

[16] T. C. P. R. V. Wanjari, “Design and Analysis of Camshaft by Changing Parameters which Causes Failure,” *International Journal of Science and Modern Engineering*, pp. Volume-1, Issue-6, May 2013.

[17] M. H. B. OTHMAN, ANALYSIS OF VIBRATION IN CAM FOLLOWER SYSTEM, PAHANG: UNIVERSITI MALAYSIA PAHANG, NOVEMBER 2009.

[18] C. moon, Cam design- a manual for engineers designers and draftmen, easton, penna: CAMCO, 1961.

[19] i. t. N. a. methods, Mechanical Behaviour and Testing Of Materials.

[20] Düsseldorf, “Efficient machining of camshaft and crankshaft,” in *Efficient machining* , Sandvikens Tryckeri, sweden, sandvic coroment, 2003, pp. 229-243.

[21] K. Deb, Optimization for engineering design, an efficient constraint handling method for genetic algorithms,.

[22] J. S. Brader, “Development of a Piezoelectric Controlled Hydraulic Actuator for a Camless Engine,” Boston University, boston, 1995.

[23] C. D. Boor, A Practical Guide to Splines., New york: Springer verlag, 1978.

[24] V. D. A. Kolchin, Design of automotive engines, Moscow: MIR publishers Moscow, 1984.

[25] “Life Assessment of the Camshaft in a Heavy Duty Diesel Engine using Flexible Multibody Dynamics,” *INTERNATIONAL COUNCIL ON COMBUSTION ENGINES*, p. Paper No. 292, 2010.