UNIVERSITY OF EDUCATION, WINNEBA,

COLLEGE OF TECHNOLOGY EDUCATION-KUMASI

DESIGN AND ANALYSIS OF A CAMSHAFT FOR MULTI – CYLINDER SPARK IGNITION ENGINE USING FINITE ELEMENT METHOD

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DECLARATION

Student's Declaration

I, BABA ZIBLIM, declare that this dissertation, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

Signature………………………………………………...

Date…………………………………………………...

Supervisor's Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education Winneba.

Supervisor: MR. CHIBUDO KENNETH NWORU

Signature………………………………………………….

Date……………………………………………………….

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DEDICATION

I dedicate this study to my father Mahama Ziblim unfortunate enough; he is resting in eternal peace. I also dedicate it to my dear wife Rashidatu, and children Jamilatu, Rahama and Hamdan, and to my best friend Abukari Mohammed, finally to my mother Ziblim Napari who laid a strong foundation to my education.

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ABBREVIATION

FEA – Finite Element Analysis

SHM – Simple Harmonic Motion

IC - Internal Combustion

FEM – Finite Element Method

GA – Genetic Algorithm

ANN - Artificial Neutral Network

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

VDI – Verein Deutscher Ingeniure

CDTM - Cam Dynamic Test Machine

DOF – Degree of Freedom

SVI – Specialized Vehicle Incoporation

RPM – Revolution Per Minute

OHC - Over Head Camshaft

CNC – Computer Numerical Control

CATIA – Computer Aided Three- Dimensional Interactive Application

ABSTRACT

Camshafts are widely used in regulating, opening and closing of valves (inlet and exhaust) in the internal combustion engines. Proper design of camshaft is required for perfect tuning between opening and closing of valves. This thesis reports an investigation that was carried out for modelling, prototyping, static and modal analysis of a multi cylinder I C engine camshaft using existing materials like chilled grey cast iron and Structural Steel and implementing material that's aluminium 6061 t6. The modelling of the camshaft was done in Autodesk Inventor and static and modal analysis was carried in ANSYS version. By using ANSYS version the static and modal analysis was done to determine the total and directional deformation, equivalent (Von Mises) stress, maximum and minimum principal stresses, natural frequencies etc. of the various camshaft materials. The results obtained from the static analysis indicate that aluminium 6061 t6 is also applicable for manufacturing of the camshaft, as the equivalent (Von-Mises) stress values of camshaft is less compared with chilled grey cast iron and structural steel. The study provides a high-performance lightweight aluminium camshaft and a manufacturing method which can enhance engine durability. The modal analysis revealed the natural frequencies and total deformation of the various materials at different modes for all the selected materials. The values of natural frequency for the aluminium 6061 t6 at different modes are higher than the existing materials.

CHAPTER ONE

INTRODUCTION

1.1 Background

A camshaft is a rotating cylindrical shaft used to regulate the injection of vaporized fuel in an internal combustion engine. These are occasionally confused with the crankshaft of the engine, where the reciprocating motion of the pistons is converted into rotational energy. Instead, camshafts are responsible for accurately-timed opening of the valves required by internal combustion engines. Camshafts have multiple cams on them, which are used to open valves through either direct contact or pushrods. A camshaft is directly coupled to the crankshaft, so that the valve openings are timed accordingly (Shobha, 2016).

Jiaping Ma (2021) investigated a cam with an isometric–trilateral profile for tube hydroforming with a hollow shaft via experiments and finite element analysis. A novel, indirect residual contact pressure measurement method is herein proposed. Hydraulic parameter effects on residual contact pressure and elastic recovery were analyzed using the theory of plastic mechanics. For hydraulic pressure below 85 MPa, increasing hydraulic parameters increased residual contact pressure nearly linearly while decreasing elastic recovery. The variety of different types of cam and follower systems depends on the shape of contacting surfaces of the cam and the profile of the follower. Rajat (2021) concentrated on dynamic analysis, fatigue analysis and modal analysis to conclude the deformation, stresses, strains and the deformation with respect to frequencies at different mode shapes and fatigue analysis was also conducted to estimate the life of the component. Finally compared simulations results with theoretically calculated values. The materials were, Stainless steel 316 and 35Ni1Cr60, malleable cast iron, EN24T and C55Mn15.

Cams are widely used in automatic machines, internal combustion engines, machine tools, etc. Camshaft is frequently called "brain" of the engine. This is so because its job is to open and closed at just the right time during engine rotation, so that the maximum power and efficient cleanout of exhaust to be obtained. Camshafts do their work through eccentric "lobes" that actuate the components of the valve train. The camshaft itself is forged from one piece of steel, on which the lobes are ground. On single-camshaft engines there are twice as many lobes as there are cylinders, Driving the camshaft is the crankshaft, usually through a set of gears or a chain or belt. The camshaft always rotates at half of crank rpm, taking two full rotations of the crankshaft to complete one rotation of the cam, to complete a four-stroke cycle. The camshaft operates the lifters (also called tappets or cam followers) that in turn operate the rest of the valve train. On "overhead valve" engines the lifters move pushrods that move rocker arms that move valve stems. Lifters can be of several types. The most common are hydraulic, mechanical and roller lifters. Hydraulic lifters are filled with oil which acts as a shock absorber to eliminate clearance in the valve train. They are quiet and don't require periodic adjustment. Mechanical lifters are solid metals and require scheduled adjustment for proper valve clearance. These are used in high-rpm applications. Roller lifters use a roller device at one end and can be hydraulic or mechanical and are used in applications where a very fast rate of valve lift is required. Revathi1 et al. (2020), discussed basic investigation of camshaft of a car. They used PRO-E and ANSYS to determine stress, strain and twisting. From the results it was found that aluminum metal lattice composites are better material for camshaft. Patel, (2015), shows that, high-performance engines need camshaft design system for computing programs for the design of different types of valve trains. This system is the development of high-quality valve acceleration curves that comply with the hydrodynamic fringe conditions of the charge cycle while providing an oscillation-attenuated valve train which subjected to little dynamic stress. Bongale et al. (2017), discussed static and dynamic conditions of camshaft. They modeled in the Solid Edge Programming and simulation is done in hyper work for lattice of the camshaft with BS-EN-10025 material. The complete investigated was done for two cases one for self-weight condition and other for outside stacking conditions.

In this work, a camshaft is designed from aluminum alloy 6061 t6 for multi cylinder spark ignition engine and static analysis carried out to ascertain the level of deformation and stress on the camshaft and the results compared to known camshaft materials like chilled cast iron and structural steel.

1.2 Statement of the Problem

Background studies indicated that there are various fields of camshaft one can explore though a lot of work have been done related to the field. 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 have calculated the maximum load that a camshaft can bare they have used different materials such as chilled cast iron and stainless steels but they have not obtained the desired results. There is always some deficiency related to the life of the camshaft. Many studies have also been carried out which are related to wear, smoothness and total change in mechanism related to camshaft. Hasan et al. (2017) and Thomas et al. (2015) stated that quality and work efficiency of a camshaft have a direct influence on automotive quality and the development of the entire automotive performance. Hasan et al.

(2017) also calculated the natural frequencies of the camshaft provided with the operating speed and pressure in design optimization of cam and follower mechanism of an internal combustion engine for improving the engine efficiency. Some studies have also been conducted in tribological analysis on the camshaft in changing the behaviour and the nature of contact between the camshaft and follower by replacing the flat follower with round one, which improved the span and the lift of follower, it was also optimised and the wear and friction between cam and follower reduced. Work has been done on development of an engine without camshaft which is a concept only. Currently some vehicles are not using camshafts**;** they use 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 from the mechanical point of view. Generally, cast iron or steel are used for the manufacture of camshaft. These materials have high densities making them retain heat for long time. For these reasons aluminium alloys are now finding their way into camshaft design and manufacture. Aluminium alloys are light weight and it is able to dissipate heat faster than the aforementioned materials. Ghana today is witnessing high influx of automobile assembling plants. These companies would require component manufacturers to feed the local automotive industry. Ghana is endowed with abundant natural resources such as bauxite. Alumina is obtained from these natural resources which becomes the basic material for equipment and component manufacture. It is required that we use local materials to solve our local problems. Hence, the decision to use an aluminum alloy such as aluminum 6061 T6 alloy for the research.

1.3 Purpose / Objectives of the Study

The purpose of the study is to design a camshaft for 4-Cylinder SI engine.

The objectives the study seeks to achieve are:

1. To design a camshaft using aluminium alloy 6061 T6 for multi-cylinder spark ignition engine;
2. To determine total deformation, equivalent (Von mises), maximum and minimum principal stress using finite element method;
3. To reduce a normal I C engine camshaft weight by 40% and
4. To cast a prototype of the camshaft.

1.4 Scope of the Study

Basically, the scope of this study will be limited to the designing, modeling and validation of the camshaft of multi – cylinder spark ignition engine for sedan using Autodesk inventor. After designing and modeling of the camshaft have been done, then analysis using ANSYS version. The project goes until detail design of the camshaft is achieved. The major output of this research is to produce camshaft from aluminum alloy 6061 T6.

1.5 Significance of the Study

This research is significant in the sense that it puts Ghana and Africa on the path to component manufacturing. Especially since Ghana has bauxite and essence of aluminium. Successful of this work will highlight the possibility of manufacturing camshafts in Ghana.

1.6 Organization of the Thesis

This study consists of five chapters. The first chapter is introduction which includes background of study, problem statement, objectives, scopes, and structure of the study. Chapter two focuses on the literature review based on the previous studies of camshaft. Chapter three will describe the methodology of the measurement of selected materials. Besides that, the details of instruments and machining used and the steps on utilization of the measuring devices will be briefly described.

The results and discussions will be presented in chapter four. The measured stresses of the camshaft included Von Mises stress, minimum principal direction stress, maximum principal direction stress, equivalent strain, safety factor and displacement will be discussed. The final chapter will consist of the summary of the study, conclusions, recommendations and suggestions for further work.

CHAPTER TWO

LETERETURE REVIEW

2.1 Design of camshaft

Camshaft is one of the key components in internal combustion engines. The performance is to control the open and close intervals of the inlet and exhaust poppet valves by its cams. Due to the cyclic impact loading on the contacting surfaces of the cam and the follower, it often gives rise to premature wear of cam profile and affects a routine run of the valve gear such as the rotational speed, valve displacement and the torque. Therefore, it demands the camshaft has not only excellent wear resistance but also adequate anti-impact toughness (Wanjari, & Parshiwanikar, 2013). According to Hasan et al. (2017), the design parameters are determined by the minimization of the maximum compressive stress at the contact area of a cam disk mechanism with translating roller follower, where the cam profiles described with the aid of cubic spline functions. Tsiafis, et al. (2012) presented a multi objective procedure based on genetic algorithms to optimize the design parameters of a disk cam mechanism with a roller follower.

According to Ogata (2019), high accelerations are needed to give rapid opening and closing, too rapid a change in acceleration will give rough operation due to the sudden changes in forces. For this reason, cam profiles are designed not to give very rapid changes in accelerations. It may also be noted that higher forces can more easily be provided by the cam than by the valve springs. It is common in higher accelerations when starting the opening of the valves and when slowing their closing at the end of the closing phase. These aspects are controlled by the cam, whereas the slowing of the valve at the end of the opening phase and the acceleration of the valve at the start of the closing phase are controlled by the valve springs. According to Guo, et al. (2010) in the analysis of anything other than a simple configuration can be quite complex. The analysis will depend upon the type of follower and the detailed geometry. Because of these difficulties with the analysis, it was common for accelerations to be determined graphically. Ogata (2019), said the use of roller-followers technology is a simple and efficient way to reduce friction in the valvetrain system with consequent reductions in consumption on Otto cycle engines for popular vehicles. The simplest assumption for analysis is to assume that the opening and closing is simple harmonic motion (SHM). Assume that the engine speed is 4000 revs/minute, this gives a cam shaft rotation speed of 2000 revs/minute (in a 4-stroke engine the cam turns at half the crankshaft speed) so the time taken for one revolution of the cam shaft is 0.03 seconds. Also, according to Sudheer, et al. (2018), 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 dynamic behavior of the system camshaft, follower, push-rod and valve is of great importance in the good working of the system (Norton 2012). From design phases, engineers can predict this dynamic behavior as a function of the different parameters of the engine valve train components. Many researchers who were interested in this research field work on different aspect like variable valve timing through computer modeling, experimental validation, and robust optimal design strategies were also considered. David, et al. (2010), showed that it is possible to develop optimal design to produce optimal valve train systems. Lethwala (2019), said to overcome the failure and to keep the cam safe from the huge impact the cam profile must be protected from wear and tear produced by the follower. Lethwala (2019) was also interested in the elaboration of camshaft lobes profiles using implicit filtering algorithm helping parameter identification and optimization in automotive valve train design. Cardona (2011), presented a methodology to design cams for motor vehicle engine valve trains using a constrained optimization algorithm in order to maximize the time integral of the valve area opened to gas flow. It was observed that profile errors can have a large influence on the dynamic performance of such high-speed follower cam systems. Sahu, et al. (2016), used a lumped mass–*spring–damper to predict the dynamic behavior of cam-valve system which gives concordant results compared with experimental tests for the evaluation of contact forces in the system. Jeon (2011), stated that with experimental and simulation results that optimizing a cam profile can increase the valve lift area while reducing the cam acceleration and the peak pushrod force. It can also avoid the jump phenomenon of the follower observed at certain points.

According to Ogata (2019), a cam mechanism usually consists of two moving elements, the cam and the follower, mounted on a fixed frame. A cam may be defined as a machine element having a curved outline or a curved groove, which, by its oscillation or rotation motion, gives a predetermined specified motion to another element called the follower. By proper location of the follower pivot, it becomes virtually impossible to jump the follower, no matter how steep the cam surface. The extreme limiting condition is to make the pressure angle small enough to prevent the cam normal force from passing through the follower pivot. Therefore, the side thrust will not exit with the property designed oscillating roller follower. Whereas as Guo (2010), stated that, the computer aided kinematic and dynamic analysis of cam and follower mechanism becomes very important for desired and required performance of the internal combustion engines. The kinematic analysis of mechanism helps in answering many questions related to motion of the follower and dynamic analysis is used to visualize the actual behavior of follower. Also, according to Sudheer, et al. (2018), it was observed that the cam is opening and closing the valve at 1200 rpm. Hence the complete valve cycle is completed in 1/3 camshaft revolution, or 0.01 sec. work was also done on evaluation of profiles for disk cams with in-line roller followers to obtained points on a cam with roller followers. From analysis it was observed that the coordinates of the Centre of the follower are required at small increments of the cam angle in which analysis can be easily programmed and depend only on the follower coordinates and not the follower type. Cams operating valves in distribution systems of internal combustion engines must ensure a suitable filling of cylinders in gasoline-air mixture for SI engines and in air for Compression ignition engines. On the other hand, for high engine speeds, valves may not have time to return to initial positions. It follows a power loss and in certain cases interference between the valve head and piston causing a broken engine.

Xiao and Zu (2016), 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 the results were compared and optimized using the GA (genetic algorithm) method for both conventional engine and the new cam drive engine.

General polynomial spline was 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’ 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. (2014), presented new approach to designing an earn-follower system, and in the process also presented solutions to problems which are faced by most of the inexperienced cam designers. Cam terminologies, cam motions and constraints were also discussed. 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)'. 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.

Bagi, et al. (2012) 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 was not only to reduce 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 was 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. (2011), 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 suggested that the assembled camshaft was a good solution to reduce the weight and increase performance of the engine. Finite Element Analysis (FEA) was used and also Finite Element Methods (FEM) was used to design the desired camshaft model and analysis. First, a simulation was run on the ordinary camshaft to define an acceptable value of the contact pressure after which they introduced their assembled camshaft. After their investigations they 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. they 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.

Folęga, et al. (2012), optimized the camshaft grinding process parameters using GA (Genetic **A**lgorithm) and ANN (artificial neutral network) methods. GA is used to improve the accuracy and speed based on the ANN model. After the experiment samples were collected 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.

Kumar and Chauhan (2015), designed an automotive engine, in the work the exact loading conditions for the camshaft was calculated and also provided the equations and the loading conditions for each component in the engine. Engine specifications were considered in the loading and provide the exact equation for the solution.

Zajaczkowski (2013), presented a mathematical model of a cam driven pattern mechanism by setting differential equations describes the behavior of the system motion of the cam and the follower taking into account the elasticity of its elements and the inertia forces resulting from the oscillatory motion of the pattern cause the speed of driving the cams to fluctuate. Sherafatnia (2014), presented automatic assembly machines which have many cam driven linkages that provide motion to tooling, the dynamic behavior of the components includes both the gross kinematic motion and self-induced vibration motion developed using solid works CAD software (Pro/Engineering). A three-mass two-degree of freedom dynamic model was created in Simulink taking into account the impact and the over-travel event of cam follower system machine to obtain improved performance. Heisler (2012), shows that for high performance engines it needs cam shaft design system for computing programs for the design of different types of valve trains. This system is the development of high-quality valve acceleration curves that comply with the hydrodynamic fringe conditions of the charge cycle while providing an oscillation attenuated valve train which subjected to little dynamic stress. Vasian (2019), came out with a mathematical model of a cam driven pattern mechanism by setting differential equations describes the behavior of the system motion of the cam and the follower taking into account the elasticity of its elements and the inertia forces resulting from the oscillatory motion of the pattern cause the speed of driving the cams to fluctuate. In order to improve the mechanical efficiency of the mechanism, an attempt was made to study the static and dynamic analysis of cam at low speed. In static analysis to study the deflection of cam and follower with respect to angular velocity and in dynamic analysis to calculate natural frequency with respect to given loading condition.

Cam and follower mechanisms are commonly used in almost every mechanical system to transmit a desired motion to another mechanical element by direct surface contact. Cam and follower mechanisms are very cheap, and simple, they have few moving parts and can be built with very small size. Generally, cam mechanisms composed of three different fundamental parts from a kinematic viewpoint.

The evolution of the cam profile design techniques is generally based on the use of splines. The motion characteristics of the cam are usually synthesized through a combination of the standard motion, parabolic, simple harmonic and cyclical functions according to the design requirements. In the past, design of the cam profile was a tedious job requiring application of graphical or analytical methods (Lanni, (2012). In most applications today, a cam profile is generated by a numerically controlled milling cutter that can be programmed to cut the cam profile, so that the desired follower motion will be generated without explicitly determining the cam profile first. A significant characteristic for a mechanical design of a cam is the sudden change in the acceleration at the profile points where arcs of different radii are joined. The profile of any cam depends on the required follower motion characteristics, normally stated in terms of displacement and velocity attributes. In the case of an automatic lathe, primitive curves forming the shape of planar cams such as dwell rise-dwell are governed by the tool tip motion characteristics required for turning a component having the desired dimensions and geometric attributes such as a spherical profile. Ceccarelli, et al. (2015), present an analytical formulation based on simple geometric relations for three circular-arc cams since this type of cams can be used in low-speed applications. In addition, circular-arc cams can be used for micro mechanisms and nano mechanisms given that very small manufacturing can be properly obtained by using elementary geometry.

In the work of Tsiaris et al. (2013), optimization of the design parameters of a cam mechanism with a flat faced follower was approached. According to Tsiafis et al. (2013), optimization satisfies constraints which are made in order to operate a cam mechanism properly. In their view, this procedure is automatic, gives results fast and it appears to be reliable. The work provides useful information for a cam mechanism synthesis. The most important conclusion of the work was that, the friction forces are analogous with the action of the follower movement. This means that in the areas of dwell the friction forces are steady, whereas in the areas of rise or return the friction forces alter in an almost similar way. Ragul (2016) did a computational analysis of stress generation and conducted a comparative study the evident results were that total deformation is high in carbon epoxy and least in spheroidal graphite cast iron, while von misses stress is greater in spheroidal graphite cast iron and least in grey cast iron. Further work was done on complex cam profile optimization which was unique cam mechanism in anew cam drive engine. First, the optimization problem was defined by taking into account multiple design specifications. The output torque of the engine was considered as the objective function. In addition, the other design specifications, including the contact stress, the pressure angle, and the radius of curvature, were selected as the constraints. Second, an analytical scenario was designed to investigate how the optimization results affects different combinations of cam profile representations and optimization methods. To this end, two types of curve representations, i.e., general polynomial spline and B-spline, was used in cam profile synthesis. Moreover, both a classical optimization technique and a genetic algorithm (GA) based method was applied to solve the optimization problem. Finally, a series of comparative studies was performed among the initial design and the optimal design of the cam profiles. Three sets of the optimal profiles were generated through manipulating different combinations of the cam profile representations and the optimization methods. The result shows that the best profiles are obtained from the combination of the B-spline representation and the GA-based method. The best profiles provide better results in terms of the output torque and the smoothness value, compared to the other two sets of optimal profiles. Moreover, the output torque generated by the best profiles increases by 28% compared to that generated by the initial profiles. At the same time, the smoothness of the best profiles is comparable to that for the initial profiles. Patel (2015), uses finite element approach to optimize the shape of flat face of existing follower into a curved face of modified follower, so that the required point contact can be achieved.

Jie (2015), developed dynamic model of valve train in multi-cylinder diesel engine to analyze the dynamics and vibrations of the camshaft. In the model, both the angular vibration and bending vibration of the camshaft were taken into consideration. The analysis results show that the bending vibration of camshaft is mainly in the normal direction of the cam tappet interfaces. Moreover, the bending vibration is mainly influenced by the overlapping of inlet cam function and exhaust cam function of each cylinder. The angular vibration of camshaft mainly focuses at the fundamental frequency and the harmonic frequency corresponding to the cylinder number.

In the paper of Arul (2017), a camshaft was designed by using theoretical calculations for the 135cc gasoline engine. Shrinkage allowance was added in this design. Also, Core and cavity for camshaft was executed. The total mould base according to standards was prepared. The manufacturing process for the camshaft generated by means of CNC programming. This modified six stroke cam enables lower engine temperature and therefore increases in the overall efficiency.

Swamulu, et al. (2015), found in their study that certain geometrical features have significant impact in improving the design features of cyclically loaded components, other standard geometric features used in machine components like threaded holes, threaded flanges, knuckles, locking pins etc. can be studied and their impact can be seen as important for guiding design engineers while development of new designs. Similarly, many other components manufactured out of rolled bars and prone to failures like axles, shafts, lead screws, ball screws etc. can be examined for their failures during service and carefully designed forgings can be developed for better grain flow at the plane of failures. The study reveals a lot of potential for field application in improving the service life of the cyclically loaded components and also reduces their cost of manufacturing.

Lindholm, et al. (2013), uses experimental method to study characterization of wear on a cam follower system in a diesel engine. Their main concern was wear analysis of cam and follower. In their study includes investigation of the running of the most important contact surfaces of a modern diesel cam follower system. The running was investigated by analyzing the changes in topography of the roller, pin and rocker arm of the fuel injector arm. In their study, the surface is assumed to be smooth. The aim of the test was to observe the behavior of the wear of standard components of an automobile engine before performing a test with coated components. During the test's moulds of the surface of the cam and the shaft were created.

Lindholm (2013), conducted a test on overhead camshaft with inlet, outlet and injector rocker arms. In this system there were several surface contacts of tribological interest, including rolling/sliding, full film, mixed and boundary lubricated regimes. The investigated surfaces in this study were the inner and outer surfaces of the roller, the pin and the rocker arm bushing all belonging to the injector pump cam follower mechanism. The tests show that the roller pin contact moves up into the mixed regime since the wear of the surface of the inner bearing is measurable. The calculation model showed that the slip, in a limited region closed to where the rocker arm reaches its upper position, was significantly higher than the remaining part of the cam cycle. Film thickness calculations showed that the cam roller contact works in the mixed lubricated regime, the slider bearing between the arm and the shaft moves over all regimes and that the roller pin contact works as a full film bearing with tendencies to enter the mixed lubricated regime.

Abreu, eta l. (2012), investigated the characteristics of a cam and follower system including contact pressure. To estimate the effect of contact pressure, the characteristics of cam and follower system were analyzed by using the finite element method. In their study they summarized some simulations in order to define an acceptable model to run 3D finite elements analysis and calculated the contact pressure. This work also aimed to assess the results of the Hertz's theory when using finite element analysis using a cylinder in contact with a flat surface and a real camshaft case. So, finite elements models allow one to assess situations that are outside the scope of the theory of Hertz in order to make a better judgment of real cases. The importance of this experiment is that it shows us how far we can be away from the correct result, if we use the wrong size, type and order of an element in a finite element analysis. The calculation of stresses in a body due to a mechanical contact for cases involving complex geometries can be evaluated only numerically. In complex situations other than, for instance, plane state of stress, there are no analytical solutions to the equations describing the stresses on the bodies in contact, so a deeper assessment of the finite element modeling is crucial for designing robust components.

Nguyen (2020) conducted an investigation into characterization of wear on a cam follower system in a diesel engine. The investigation focused on the effect of cam and follower materials and their thermal and thermo chemical treatment on cam and follower functional properties. During the investigation, the preferred material for a camshaft mating with a slide cam follower was grey metallurgically hardened cast iron. And the mating follower was made of chilled cast iron, hardened and tempered. The investigation was carried out on a laboratory bench equipped with an engine head with a camshaft, followers and systems creating the conditions necessary for a routine run of the valve gear. Cam wear was defined by comparing the profile lifts of the cams. It often concerns cams mating with a roller follower where the wear may be increased, particularly due to the occurrence and propagation of cracks. With respect to the geometry and kinematics of combustion engine valve gear, it is generally assumed that the value of Hertzian pressure has a direct effect on the pitting wear value.

In the analysis camshafts were made of nodular cast iron, surface hardened, ion nitride and nitrosulphurized, and those made of grey chilled cast iron are mated with followers made of chilled grey cast iron and hardened steel. The investigation result shows that the formation of a nitrided layer on the hard and thick matrix of cams ensures its small radial wear. The cam undergoes smooth abrasive wear. Follower also undergoes smooth abrasive wear of a small value. The application of sulfonitriding is not recommended because of the increased wear on the cam and follower despite smaller resistance to motion. The explanation of the results obtained for the cam follower kinematic pair wear arises from the Hertzian theory as well as from the occurrence of tensile stresses at slide contact. At contact points, tensile stresses behind the contact surface of the C2 modular cast iron cam and the grey cast iron follower, hardened during casting, may have attained a value exceeding their tensile strength. Internal stresses were also of tensile nature at small depths, which helped the process.

Ghazalli (2017), studied the contact stress analysis of cam and follower using finite element analysis. The project aims to determine the stress concentration on the cam and followers during normal operation. Moreover, this project used the cam, rocker arms, valve lifter, exhaust valve and accessories used in 4G13 engine. The finite element analysis was done for determination of stress concentration during 30 degree of cam where the roller fully climbing the cam and during maximum exhaust valve lift. In the analysis, the typical values for coefficient of friction, materials, and spring rate were used. The result from finite element analysis showed that the maximum stress concentration occurred at rocker arm that leads to the failure of the component. Value for maximum stress was over the allowable stress for rocker arm material. Other components were approximately safe where the maximum stress is not over the allowable stress for components.

Paradorn (2017), investigated an impact model for the industrial cam-follower system using simulation and experiment. From this model, an insight into proper design of systems with deliberate impact was developed through computer modeling. To attain more precise representations of a simplified industrial cam follower system model was constructed in Solid Works CAD software. A two mass, single-degree-of-freedom dynamic model was created in Simulink, a dynamic modeling tool, and validated by comparing to the model results from the cam design program, DYNACAM. After the model was validated, a controlled impact and over-travel mechanism was designed, manufactured, and assembled to a simplified industrial cam follower system, the Cam Dynamic Test Machine (CDTM). Then, a new three-mass, two-degree-of-freedom dynamic model was created. Once the model was simulated, it was found that the magnitude and the frequency of the vibration, in acceleration comparison, of the dynamic model matched with the experimental results fairly well. During the investigation an impact and over-travel mechanism was designed, manufactured, and assembled. The most important requirement was to ensure that the impact and over-travel mechanism was implemented and the events were consistent and repeatable.

The design must not exceed the available space or interfere with the existing machine as well as minimizing the modification made to the existing parts. Adjustability of the over-travel distance was highly desirable because this will allow the user to change the over-travel distance, impact velocity, and force exerted on the hard-stop. The over-travel spring must prevent the separation of the impact mass and the intermediate mass until impact occurs to ensure that the condition experienced in the actual system is maintained in the experiment. Lastly, the force experienced by the impact mechanism was obtainable through experiment, which is done by placing the force sensor where the striking impact occurs. The result of comparison between the experimental and simulated showed that the experimental and simulated acceleration of mass, the maximum magnitudes of the first and third impacts match relatively well, even though the shapes after impact do not. The main reason for this discrepancy was the lower degree-of-freedom of the simulated system versus the real system. By reducing degree of freedom (DOF), higher modal characteristics of the links were excluded from the model. The maximum magnitudes of the simulated acceleration for the second and fourth impacts were 1.32 times smaller than the experimental acceleration.

2.2 Stress analysis to determine highly stressed regions and total deformation of the camshaft

Contact stresses between curved bodies in compression are often termed "Hertzian" contact stresses after the work on the subject by Hertz in 1881. This work was concerned primarily with the evaluation of the maximum compressive stresses set up at the mating surfaces for various geometries of contacting body but it formed the basis for subsequent extension of consideration by other workers of stress conditions within the whole contact zone both at the surface and beneath it. It has now been shown that the strength and load carrying capacity of engineering components subjected to contact conditions is not completely explained by the Hertz equations by themselves, but that further consideration of the working conditions is an essential additional requirement. There are great deal of researches and number of literatures on cam and follower analysis that has been published. Generally, their major concerns are on the analysis of cam and follower stresses, failure, contact pressure, realization of follower motion of cam and follower system, kinematic and dynamic analysis, modeling, which are very useful for optimal design of cam and follower system. They have used various approaches and means to attain their main intention.

Dhavale and Muttagi (2012), discussed stress analysis and the fracture analysis of the cam shaft in an engine. Derived some relations and results by taking the specific material for the camshaft manufacturing and analysed the results using the finite element methods and software. They also prepared a dynamic model for FEA analysis. Different alloys with specific weight elements as carbon, silicon, manganese, molybdenum, nickel, aluminium copper, titanium, magnesium, sulphur and phosphorus with the following percentages 3.42%, 2.33%, 0.296%, 0.010%, 0.038%, 0.010%, 0.518%, 0.028%, 0.026% and 0.009% respectively, was used for the determination of the stress concentration level at the fracture region by the finite element method. The failure 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.

Dhavale and Muttagi (2012), also studied modeling and fracture analysis of camshaft to design good mechanism linkages and the dynamic behavior of the components was 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 were studied. Failure occurred at the journal location, where there is a stress concentration. It was recommended that, 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.

Kumar and Mamilla (2014), modeled, 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. From the operation, maximum design strength was 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 was 720 N/mm2, then the factor of safety comes within that safety limits.

Andresen and Singhose, (2012), investigated the cause of unwanted vibration and force during the cam operation. The unwanted vibration in cam-follower systems increases operating forces and costs. Importance of shape function of a cam profile was also investigated. The investigation was done using real-time command modification method. Experimental apparatus for results and demonstration was manufactured. 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.

Jasdanwalla, et al. (2018), had done camshaft analysis in the ANSYS software and calculated the loading conditions of the camshaft on the bases of the engine specifications also formula for the total deformation in the camshaft for the FE analysis were used and ANSYS software for a load of 1134 N had a deflection of .00059mm in the camshaft when specific material was used. The results were calculated manually and compared with the analytical results calculated using software. Jasdanwalla, et al. (2018) also analysed the frequency and the vibration of the cam and follower mechanism. Methods and exact boundary conditions were provided that may also apply to the system that is using the cam and follower mechanism.

Escobar (2019), conducted fatigue analysis of Specialized Vehicles Inc. (svi) tested cam lobe, the research objective was a better understanding of the grinding process and its effect on the work piece residual stress state, more important for design engineers. The analysis includes the life prediction of cam lobes, failure of cam and crack analysis. From the analysis the following was concluded; Cracking occurred almost exclusively in the opening ramp of the most abusively ground lobes. It was induced by tensile residual stresses generated during grinding, and to a lesser extent by dynamic loading. Cracks were confirmed to propagate as deep as 300ml below the surface of the lobe. Residual stress relaxation was measured and confirmed to occur in the most abusively ground lobes. It was induced by tensile residual stresses. Generated stresses were reduced and shifted deeper into the material. These residual stresses stabilized after a certain number of cycles, regardless of the level of grinding.

Two types of cracks were identified after simulated engine testing: straight and pitted. Nucleation of straight cracks occurs during grinding by the localized thermal expansion of the steel. Pitted cracks are nucleated by the synergistic effect of subsurface tensile residual stresses and impact loads generated by the follower during testing. Propagation of straight cracks has fatigue characteristics, with “lava flow” fracture surfaces suggesting lateral rubbing of crack surfaces due to cyclic loading. Propagation of pitted cracks is closely related to the process of pit formation (pieces of material are flake off due to impact loading, leaving behind a pit). These cracks propagate by pits joining together.

Wanjariand Parshiwanikar (2013), work on shaft with dynamic numerous parameters which can causes failure. The work was done to determine the strain concentration on cam and follower throughout their traditional operation. Shaft in TATA expedition dicor two.21 engine was used. Pro-E and ANSYS software package were used for the determination of stress concentration. Values of constant of friction, material and spring rate were additionally used. The result from finite component analysis (FEA) showed that the utmost stress concentration occurred at shaft joins that results in failure of the part. It was concluded that heat flux is most within the metallic element alloy as compared to alternative materials however the values of shear stress and total deformation was additionally high in metallic element alloy.

Leeuwen, et al. (2019), describes some results of local film thickness and temperature measurement in an eccentric cam-flat follower contact by means of miniature vapour depositor thin layer transducers. Complex transducer patterns were realized by employing photo lithography, allowing local measurements in axial direction and a full film was developed at relatively low speeds. Film thickness and temperature at both sides of contact differ appreciably, thus invalidating the assumption of line contact. And the paper considers capacitance measurement under misalignment and temperature measurement. Considering the above conditions, they concluded the following: if the contact has some misalignment, mixed film condition may prevail at the heavy load side. The rise in film temperature can become high, leading to chemical reaction layer formation. The capacity measuring technique allows an examination of the extent and thickness of these layers, and if good alignment was obtained after incorporating self-aligning elastic hinge support, then measurement temperature variation will not be high, but need to be included in the film thickness calculations. Probably starvation occurs, because calculated film thickness was still too high. The transducers worked well and have satisfactory life expectancy.

Hua, et al. (2017), analysed fatigue failure within a shaft using crack modeling technique. The strategy used a linear elastic finite component analysis to derive identical stress intensity factor (K) for stress concentrations in numerous parts. K is calculated while not introducing cracks into the components. The strain field around the most stress areas examined and compared to a typical center-cracked plate. Fatigue is often assumed to occur if the cyclic worth of K exceeds that of crack propagation threshold. The part was clamped at one end and so loaded either in bending or torsion, to supply failure at the chosen location. The information for the material was obtained. Sandglass specimens loaded in axial tension or compression and additionally hardness was measured to record the variation as a function of distance from surface. They got the results for material fatigue limit.

Rivola, et al. (2007), did modeling, style and finite component analysis (FEA) on shaft. This was a vital step in fixing optimumization problems of various shafts and knowing dynamic behavior of the shaft. During the paper, a model was created for exploitation of the essential dimensions with accessible background information like power to be transmitted, forces acting over the shaft by means of valve train throughout the running at most speeds. To avoid fatigue failure, determination of tangible load values was very important task for rotating members.

Horvat and Surfiz (2011), have done the modal as well as fatigue analysis on a shaft. As the shaft rotates at high speed it always fluctuates. Owing to this, modal and fatigue analysis was disbursed to confirm safety and additionally to work out lifetime of the member. For this purpose, they used an air mass piston pump system. This pump was then tested on the cam that simulates the engine conditions by the assistance of shaft. Analysis was then disbursed on a shaft of high piston pump. During this analysis the shaft was shape in CATIA V5 and Hypermesh V9 software package in STEP format for meshing purpose.

2.3 Reduction of weight improved camshaft material

Wanjari, and Parshiwanikar, (2013), 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 tried to change the material of the camshaft so that the thermal flux and the shear stresses may be balance in some satisfactory regions. It was found that the values of shear stress in grey cast iron are minimal and the value of total deformation is low for forged steel. The maximum values of loads 3500N and 5000N obtained maximum value of shear stress and total deformation. These values 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.

Dave and Kothari (2013), 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. Calculation was also done on hydraulic pressure and the load on the cam due to the cylinder and calculated the deformation in cam. Total deformation in the exhaust cam, inlet cam and the fuel cam were calculated simultaneously.

Revathi (2020), carried out dynamic, fatigue and modal analysis of a 6-cylinder camshaft for different selected materials by varying forces, angular velocity, and torque with respect to time. From the dynamic analysis, fatigue analysis results observed indicated that, by increasing the force, angular velocity and torque with respect to time. The stress, strain and deformation values increased for different material though some materials have more young's and ultimate strength than the existing malleable cast iron. The minimum stress value and maximum factor of safety was obtained by observing modal analysis result table among different selected material, the maximum natural frequency obtained, was less than theoretically calculated value and factor of safety.

Chandra (2014) analyzed and evaluate camshaft using traditional materials cast iron and forged steel. Material optimization was also carried out to replace the traditional material with new composite alloys. Static analysis was also conducted to find the displacement and stress due to loads and then modal analysis to determine the frequency values due to its geometric shape and material property (natural frequency's). After model analysis, dynamic frequency analysis was done to determine the displacements due to external vibrations. According to the results obtained, composite alloy is good for camshaft manufacturing. Comparison of materials with the values of total deformation, equivalent (Von-Mises) stress and equivalent elastic strain acquired from the static structural analysis of camshaft C55 steel has less value of total deformations and equivalent elastic strain compared with the mild steel. Hence C55 steel can be chosen as an alternative material for camshaft (Ragothaman, 2018)

Ragull (2016), came out with experimental results from testing the camshaft under static load containing the stresses and deflection. Testing was done unidirectional on different materials like nodular iron, ductile cast iron and also epoxies material. The materials were analyzed and ductile cast iron selected and compare to the present material of nodular iron because the breakage of nodular iron is higher than the ductile cast iron, and also nodular cast iron are not commonly used for camshaft in vehicle because the cost of the material is slightly high than the ductile cast iron.

From the review it has been noticed that Cam design has changed dramatically over the past two decades by taking the advantage of the tremendous advance of computing devices and mathematics tools especially for splines. In recent years, the trend of modern cam design is that splines are replacing polynomials as the mathematical representation of the cam profile because of their versatility, ease of application and flexibility. Follower motion curve shape can be easily changed by varying the control points that define the curve. Researchers have done a lot of work related to the camshaft they have calculated the maximum loads and the strength of camshaft materials that can be used for the manufacturing of the camshaft. They have also calculated the lifespan of the component according to the research works that has been reviewed, work is done related to materials and wear, smoothness, replacement and total change in mechanism related to camshaft.

CHAPTER THREE

METHODS AND MATERIALS

3.1. Material Selection

The material selected for the study was aluminium 6061 t6 alloy and the reinforcement used was silicon carbide (5% wt.) of size 50 μm each. Camshafts can be made out of several different types of material. Some existing materials are chilled grey cast iron, structural steel etc. aluminium 6061 t6 is selected because of its notable properties such as light weight, high strength, high specific modulus, high fatigue strength, high hardness, low density etc. as shown in Table 1. The 6061 t6 aluminium alloy is primarily composed of aluminium, Magnesium and Silicon. Its other metallic elements include iron, copper, chromium, zinc, manganese and titanium, in descending order of quantity (6061 aluminium is 97.9% Al, 0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu.). Earlier alloys had been susceptible to stress-corrosion cracking, but the addition of a small amount of chromium made this alloy highly resistant to corrosion.

Table 1: Properties of Aluminium 6061 t6

Property	Value	Units
Elastic Modulus	68.9	Gpa
Poisson's ratio (ν)	0.33	Non
Bulk Modulus	147560	Mpa
Shear Modulus	26	Mpa
Density (ρ)	2.70	g/cm^3
Tensile Strength	310	Mpa
Compressive Strength	125	Mpa
Yield Strength	276	Mpa
Thermal expansion coefficient (α)	2.32×10−5	K
Thermal conductivity (k)	151–202	W/(m-K)
Specific heat capacity (c)	897	J/(Kg-K)

Table 2: Properties of Chilled Grey Cast Iron

Property	Value	Units
Elastic Modulus	193000	Mpa
Poisson's Ratio	0.27	Non
Shear Modulus	75984.8	Mpa
Bulk Modulus	139868	Mpa
Density	7.3953	g/cm^3
Tensile Strength	550	Mpa
Compressive Strength	140	Mpa
Yield Strength	137.9	Mpa
Thermal expansion Coefficient	4.3	K
Thermal Conductivity	16.3	W/(m-K)
Specific Heat	500	J/(Kg-K)

Table 3: Properties of Structural Steel

Property	Value	Units
Elastic Modulus	190000	Mpa
Poisson's Ratio	0.27	Non
Bulk Modulus	158330	Mpa
Shear Modulus	74803	Mpa
Density	7.872	g/cm^3
Tensile Strength	413.6	Mpa
Compressive Strength	140	Mpa
Yield Strength	275.74	Mpa
Thermal Expansion Coefficient	3.2	K
Thermal Conductivity	47	W/(m-K)
Specific Heat	510	J/(Kg-K)

The design calculation below involves Honda XL 2014 sedan.

3.2 Engine Specifications

Engine type; In – line 4 – cylinder OHC.

Engine Block / Cylinder Head: Aluminum Alloy

Engine displacement (L/cc):2.4 / 2356

Horsepower at rpm: 185kw at 6400 rpm = 185kw at 6400 rpm Torque (1b – ft) at rpm: 181 at 3900 = 245.4Nm at 3900 rpm

Bore and stroke (mm): 87 x 99.1

Compression ratio: 11.1: 1

Inlet valve opens = 10^0 BTDC = 10^0 BTDC

Inlet valve closes = 46^0 ABDC = 46^0 ABDC

Exhaust valve opens = 51^0 BBDC = 51^0 BBDC

Exhaust valve closes = 15^0 ATDC = 15^0 ATDC

3.2.1 Theoretical calculations of camshaft

Area of the piston (A_ρ) = $\frac{\pi D^2}{4}$

Where D is the diameter of the bore

Therefore $A\rho = \frac{\pi(87)^2}{4}$ = 5944.68mm^2

Velocity of the piston ($V\rho$) = $\frac{2\ell N}{60}$

Where ℓ = stroke of the piston and N = speed of the engine.

$V\rho = \frac{2 \times 99.1 \times 6400}{60} = \frac{1268480}{60} = 21141.33 mmIs = 21.141 mIs$

3.2.2 Pressure calculation (maximum pressure develops in engine cylinder)

Density of petrol (C_8H_{18}), $\rho = 750 Kg/m^3 = 750 \times 10^{-9}$kg /mm^3

Operating temperature, T= $293.15k$

Mass $= Densitynn\ of\ petrol \times volume = 750 \times 10^{-9} \times volume$

The total engine volume = $2356cc$

Volume per cylinder $= \frac{2356}{4} = 589cm^3 = 589 \times 10^3 mm^3$

Mass= $750 \times 10^{-9} \times 589 \times 10^3 = 0.44175\ kg = 441.75 \times 10^{-3} kg$

Molecular weight of petrol, M= 114.228×10^{-3}kg/mole

Gas constant for petrol, R= $\frac{universalgasconstant(air)}{molecuarweightofpetrol}$

Universal gas constant (air) = 8314.3 J/k

Gas constant for petrol, R= $\frac{8314.3}{114228 \times 10^{-3}} = 72.79 \times 10^3$ J/kgmole. k

From Gas law equation

PV= MRT

P= $\frac{MRT}{V} = \frac{441.75 \times 10^{-3} \times 72.79 \times 10^3 \times 293.15}{589 \times 10^3} = \frac{9426233.12}{589 \times 10^3} = 16.00$

$$P = 16\ N/mm^2 = 16MPa$$

Therefore, the camshaft is designed for the maximum cylinder gas pressure of 16MPa.

Pressure P = 16 N/mm^2 = 16 MPa

Engine Compression ratio = 11.1: 1

3.2.3 Valve and accessories specification

Mass of valve (mv) 100gm = 0.1Kg

Valve head diameter = 19 mm

Valve inertia force Fi = - 191.861N

Valve spring stiffness (K) = 18 N/mm

Rocker arm ratio (r_1 / r_2)

r_1 = 61 and r_2 = 42

3.2.4 Determination of force acting on the camshaft

1. Force exerted by valve (Fe) = valve inertia force * mass of valve

$F_e = F_i * m_v$ = -191.861 * 0.1 = -19. 1861 N

2. Volume Calculation

Compression ratio = 11.1: 1

Let

V_c = Clearance volume

V_s = Swept volume

Therefore,

Compression ratio = $\frac{sweptvolume+clearancevolume}{clearancevolume}$

$$R_{c=}\frac{v_s + v_c}{vc}$$

Swept volume (Vs) = $\frac{\pi d^2}{4} xL$ Where d = diameter of the bore and L = Length of stroke

Swept volume V_s= $\frac{\pi\times(87\times10^{-3})^2}{4} \times 99.10^{-3}$

V_s= 5.94468×10^{-3} 99.1×10^{-3} = $5.89117659 \times 10^{-4}$ m^3 = 5.891×10^{-4} m^3

But

$R_c = \frac{V_s+V_c}{V_c} = 11.1 = \frac{5.89117659\times10^{-4}+V_c}{V_c}$

$11.1\ V_c - v_c = 5.89117659 \times 10^{-4}$

$V_c(11.1 - 1) = 5.59117659 \times 10^{-4}$

$V_c = \frac{5.89117659\times10^{-4}}{10.1} = 5.833 \times 10^{-5}$m^3

3.2.5 Total cylinder volume

$V_t = V_s + V_c = 5.891 \times 10^{-4} + 5.833 \times 10^{-5} = 6.4743 \times 10^{-4} m^3$

4. Gas force on the valve (F_g)

$F_g = \frac{\pi d_v^2}{4} \times p$ = Valve head area × gas pressure

$F_g = \frac{\pi (19)^2}{4} mm^2 \times 16 \ N/mm^2$

$F_g = 283.529 \times 16 = 4536.5$ N

3.2.6 Force on the camshaft (F_{cs})

F_{cs} = gas force × rocker arm ratio

$F_{cs} = 4536.5 \times (^{61}/_{42})$

$F_{cs} = 4536.5 \times 1.452$

$F_{cs} = 6588.7N$

3.3 Modelling of Camshaft in Autodesk Inventor

The camshaft for a Four-Cylinder Spark Ignition Engine was modelled using the dimensional parameters from the existing one. The model was created in modelling software Autodesk Inventor which is excellent CAD software, which makes modelling so easy and user friendly and then imported into ANSYS workbench for the analysis. The modelled camshaft is shown in figure 1.

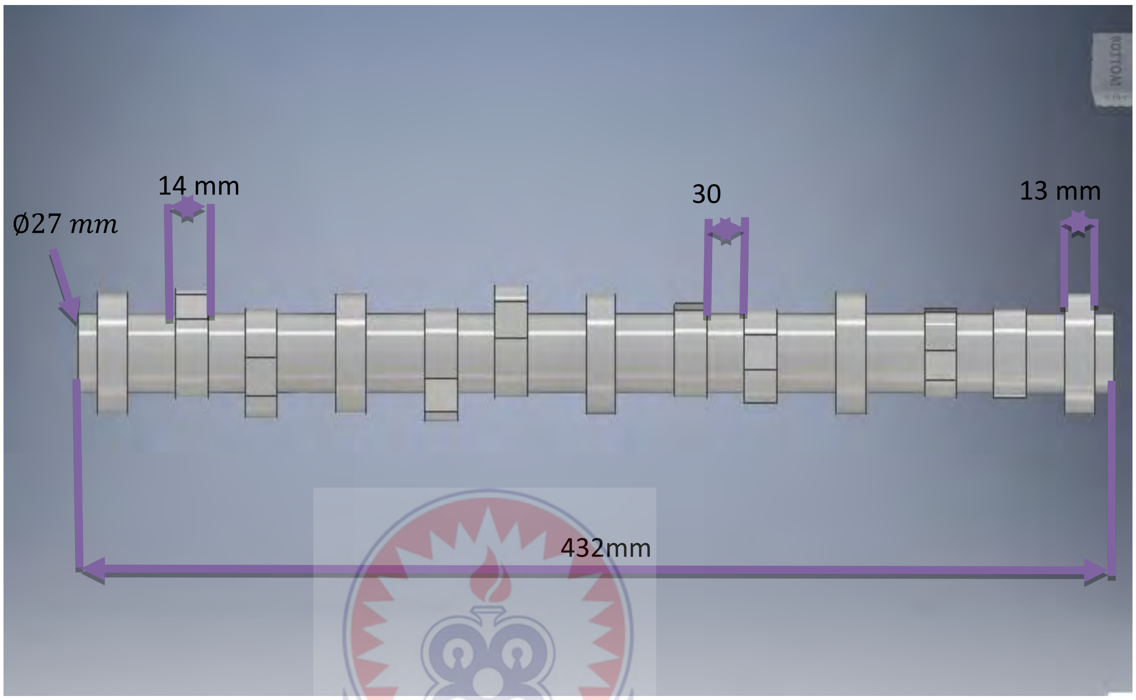

Figure 1: Model Camshaft

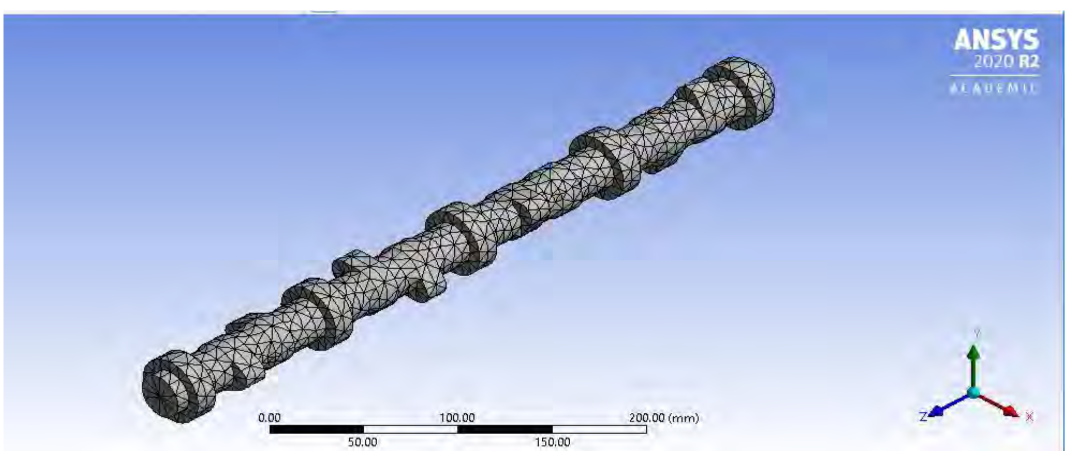

Figure 2: Component Mesh in ANSYS

3.4 Numerical Procedure

Analysis is the part in which we test whether the component will work in the specific conditions or not with desired improvements and modifications. In the real world, no analysis is typical, as there are usually facts that cause it to differ from others. However, the procedure shown in Figure 2 was used for the analysis.

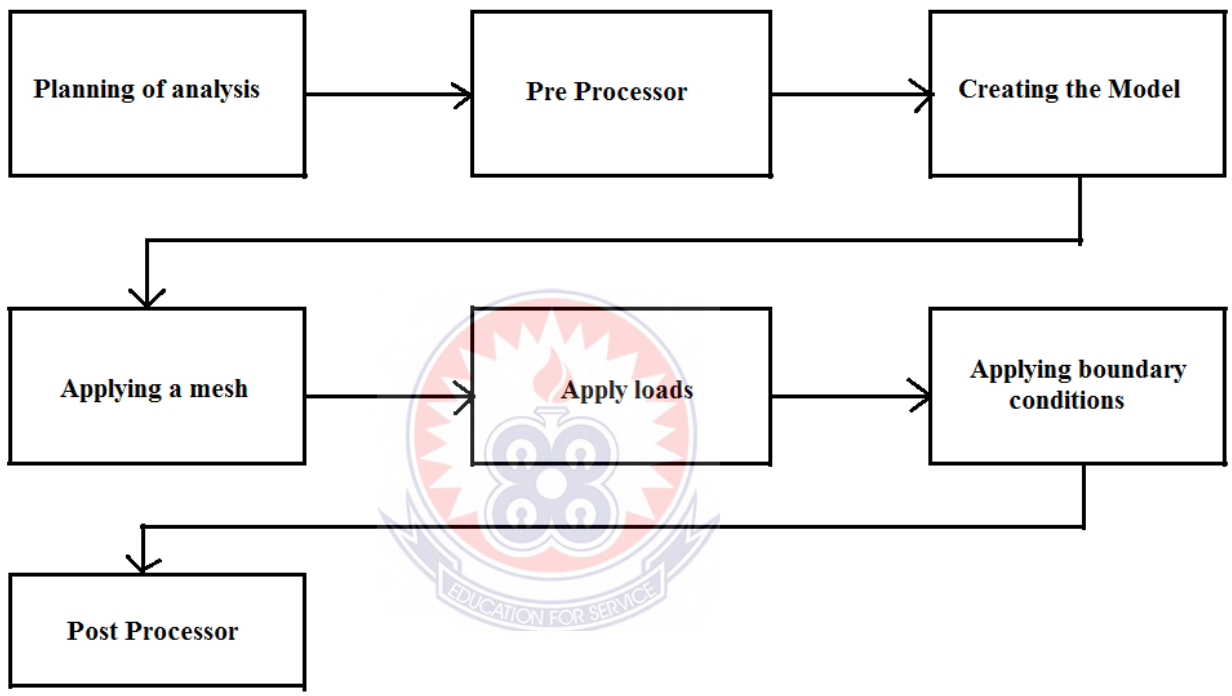

Figure 4: Analysis Procedure and the Steps Involved in the Process

3.4.1 Planning the Analysis

The main motive behind a FE analysis is to model the behaviour of a structure under an arrangement of loads. To plan the analyses, the loads or facts which are going to affect the model was considered and ignore the loads or facts which are not going to affect the final results. The extent of accuracy of the outcomes depends on the level of planning of the analysis that has to be carried out.

3. 4.2 Pre-Processor

At this stage the name of the file and the problem was provided. Providing a name to a file is considered as optional but it is very useful when you are dealing with the various analyses on the same project, it also provides the difference between the various iterations of the processes which are applied on the same base model.

3.4.3 Creating the model

The model was first drawn in the 2d sketch space in the appropriate units (mm). The model was then converted into 3D space using Autodesk Inventor. It was then imported to ANSYS another CAD drafting package by the neutral file formats. Fortunately, 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 remain the same if it is not so the results may go out of scale and will not match the final expectations.

3.4.4 Applying a Mesh

Structured meshing was selected for the study because this type of mesh is characterized by its regular shape arrays of the elements which are connected to each other. The regularity of the connectivity allows space to be conserved since neighborhood relationships are defined by the storage arrangement.

Meshing is a process used to divide a large model into the small discreet elements which have a defined shape and size that can be controlled by the user. On the camshaft 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 a very tedious task. To make all these calculations easy, meshing divides such geometry into small elements for which there is definite formulae and functions to calculate these results. Then all these results are then integrated to get the total solution for the geometry.

3.4.5 Applying Load

A fixed-point load of 6588.7N was applied to the modeled camshaft during the static and modal analysis which is equal to the maximum force exerted on the camshaft to open and close the valves during induction and exhaust strokes for the smooth operation of the engine.

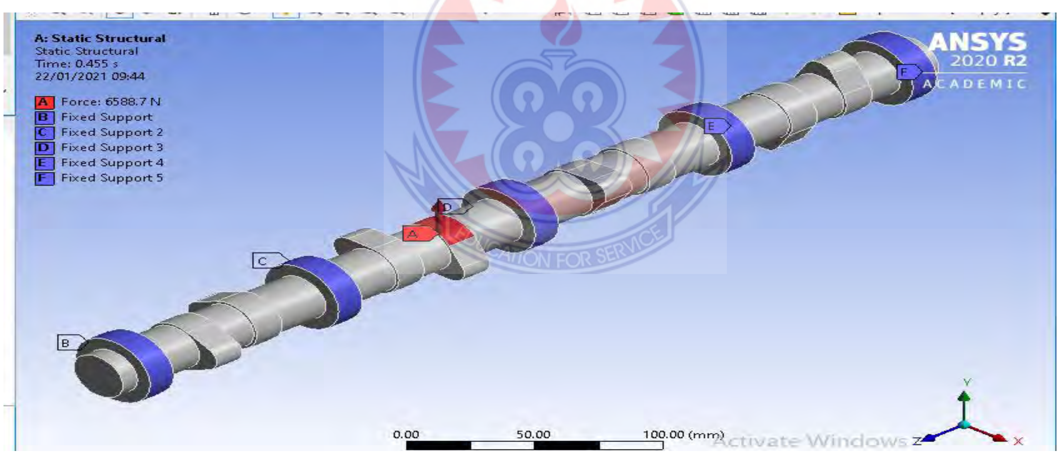

Figure 3: Fixed Point Load Camshaft

3.4.6 Applying Boundary Conditions

If load is applied to a model, it's likely to accelerate. In order to stop it from accelerating infinitely through the computer's virtual ether, at least one constraint or boundary condition must be applied. In this study all the camshaft journals were constrained to prevent it from accelerating. In this, the boundary condition was specified to act in only (y), direction. The applications of correct boundary conditions are critical to the accurate solution of the design problem.

3.4.7 Post-Processor

The FE solver was isolated into three primary parts, the pre-processor, the mathematical engine, and the post-processor. The pre-processor peruses in the model made 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 in the pre-processor will gripe and cross out the call to the mathematical engine. On the off chance that the model is amended the solver continues to shape the component solidness network for the issue and calls the mathematical engine which computes the outcome (dislodging, temperatures, weights, and so on.) The outcomes come back to the solver and 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 is sent to an outcome record, which would be perused by the post-processor.

3.3. 4 Casting of the Camshaft

Production of composite materials of standard quality is influenced by correct choice of operating parameters, such as melting temperature, mixing speed, preheating temperature of reinforcing material, and the like. The procedure that was applied in the preparation of the composite is as follows. About 1 kg of Al6061 t6 alloy was heated to a melted state in a graphite crucible using an induction resistance furnace. The melt temperature was 750 °C.

After the alloy was completely melted, a Stainless-Steel stirrer was introduced into the molten alloy, consisting of two blades coated with Boron Nitride non-stick paste, and the mixing process began. Boron nitride non-stick coatings were used to prevent the sticking of molten metal to the inner surface of the crucible. The mixer was rotated at 500 rpm for 30 min. The immersion depth of the agitator was maintained at about 2/3 of the depth of the molten metal. During mixing, a 5% by weight fraction of the pre-heated reinforcing particles SiC was added to the vortex formed with stirring. Before this, the reinforcing particles were preheated to 250 °C for one hour. After adding the particles to the melt, the composite alloy was poured into a sand-casting mould and cooled to ambient temperature. The preform was then removed from the mould. Figure 3 shows the casting process.

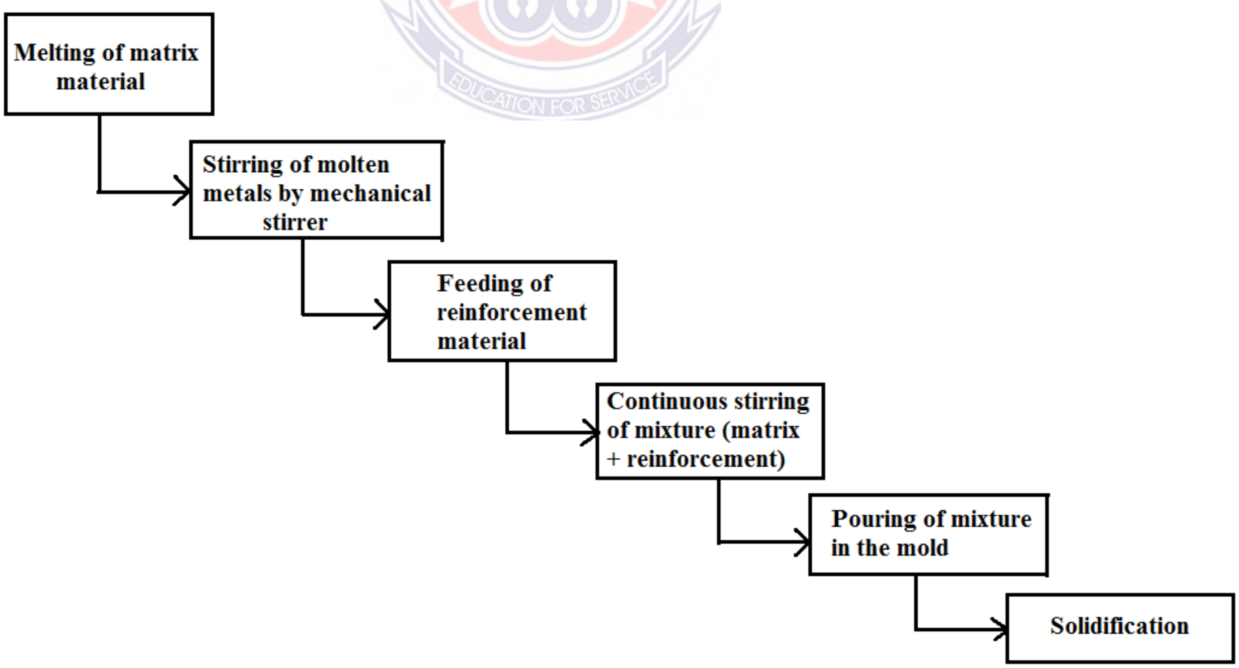

Figure 5: Process of Casting the Camshaft

Figure 6: Pouring the Alloy Composite in to Mould

Figure 7: Cast Aluminium 6061 t6 Camshaft

3.5.1 Machining Process

After casting, the work piece was machined by ordinary lathe in required dimensions. The machining process was divided into three: processing stage, cam surface roughing, and cam surface finishing.

3.5.2 Processing Stage

The machining stage was divided during the machining process, and the machining process was analyzed, fortunately there was no quality problem in the processing of the camshaft.

3.5.3 Cam Surface Roughing

(a) Roughing: This involved roughing each support journal, timing gear journal and threaded journal outer circle.

(b) Semi-finishing: This involves rough grinding the cam.

(c) Finishing: Fine grinding timing pin journal and thrust surface, four bearing journals outer circle, fine grinding cam, polished support journals and cams.

Positioning: Position a bearing journal end face in an axial direction using a timing gear and a support shaft outer circle as a positioning reference and a roller- type auxiliary support was used in the machining.

3.5.4 Cam surface finishing

The accuracy of the cam profile was improved by controlling the diameter of the grinding wheel. The entire cam on the camshaft was continuously coarsely ground after one installation at a high feed rate of 60m/s, and finish grinding all the cams at a grinding speed of 30m/s.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Analysis

After modeling, the camshaft was imported into ANSYS version for static and modal analysis. From the analysis total deformation, equivalent elastic strain, equivalent (Von Mises) stress, maximum principal stress, minimum principal stress and factor of safety was established for the three materials. Modal analysis of the camshaft was also done in which the total deformation and natural frequency of the camshaft were calculated.

4.2 Static Analysis

A static analysis is used to calculate the effects of steady loading conditions ignoring the effects of inertia and damping. In static analysis loading and response conditions doesn't vary with time. The input loading conditions that can be given in a static analysis are moment, applied force and pressure and the output can be displacement, forces in a structure, stress and strain. If the values obtained in static analysis crosses the allowable values it will result in the failure of structure.

Figure 8 to 14 shows the simulated results of chilled grey cast iron in relation to total deformation, directional deformation, equivalent (Von Mises) Stress and strain etc.

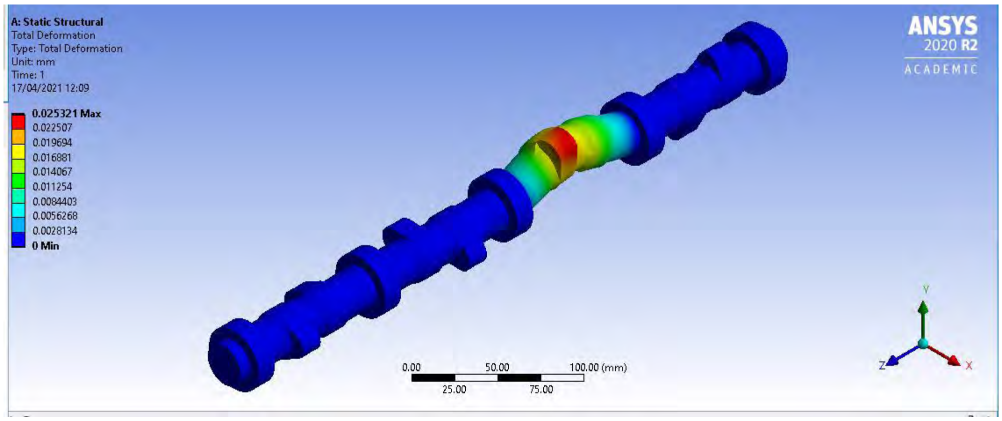

Figure 8: Total Deformation of Chilled Grey Cast Iron

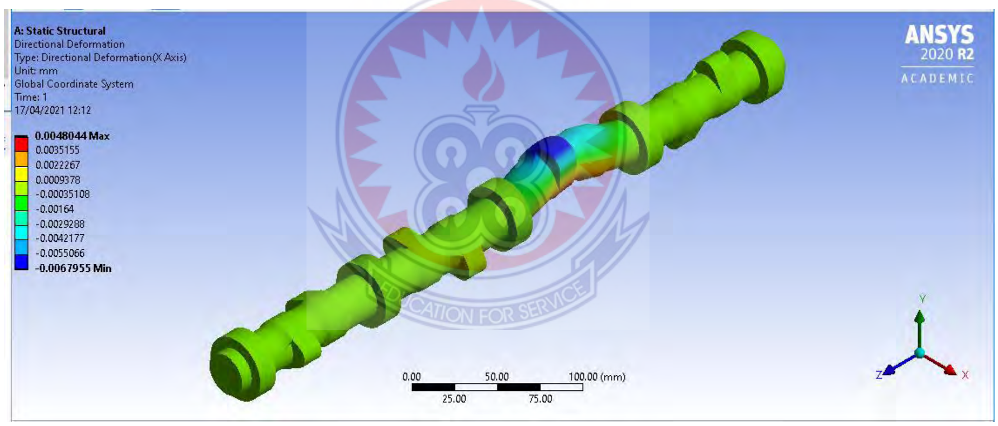

Figure 9: Directional Deformation of Chilled Grey Cast Iron

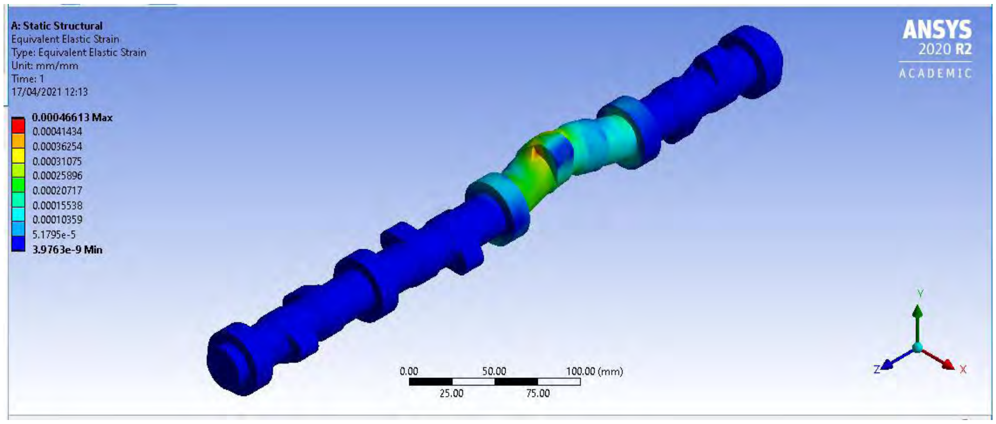

Figure 10: Equivalent Elastic Strain of Chilled Grey Cast Iron

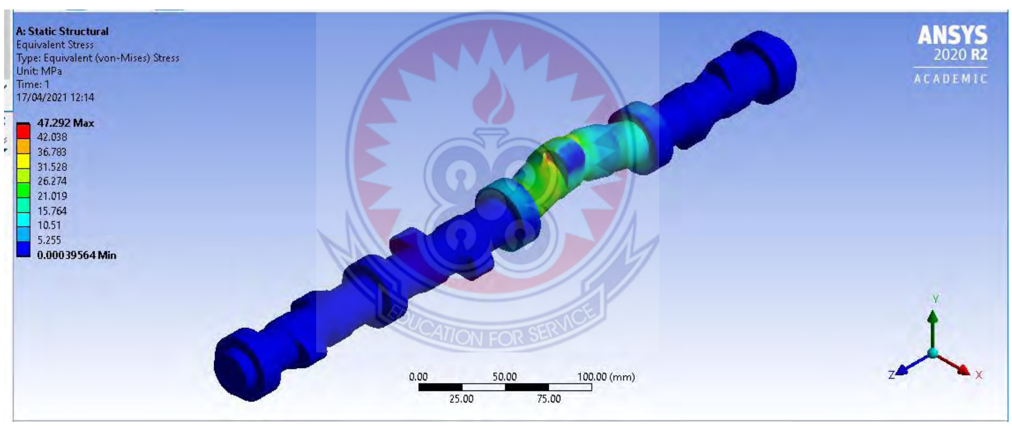

Figure 11: Equivalent (Von Mises) Stress of Chilled Grey Cast Iron

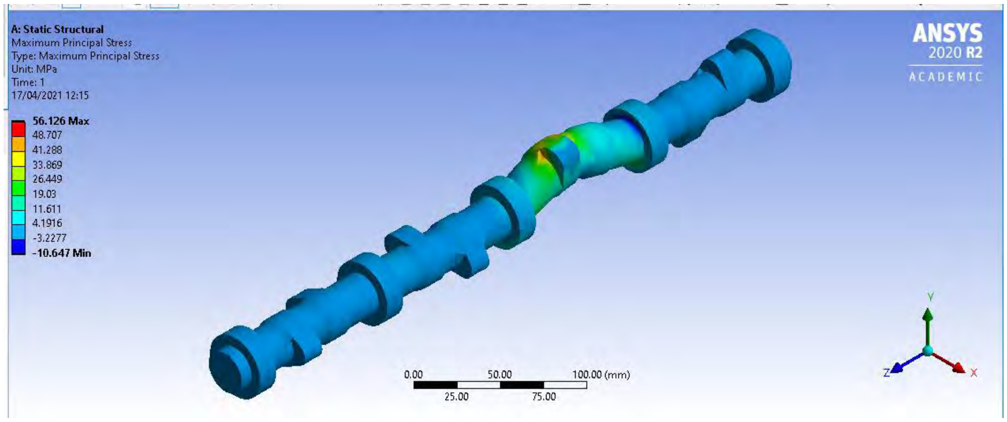

Figure 12: Maximum Principal Stress of Chilled Grey Cast Iron

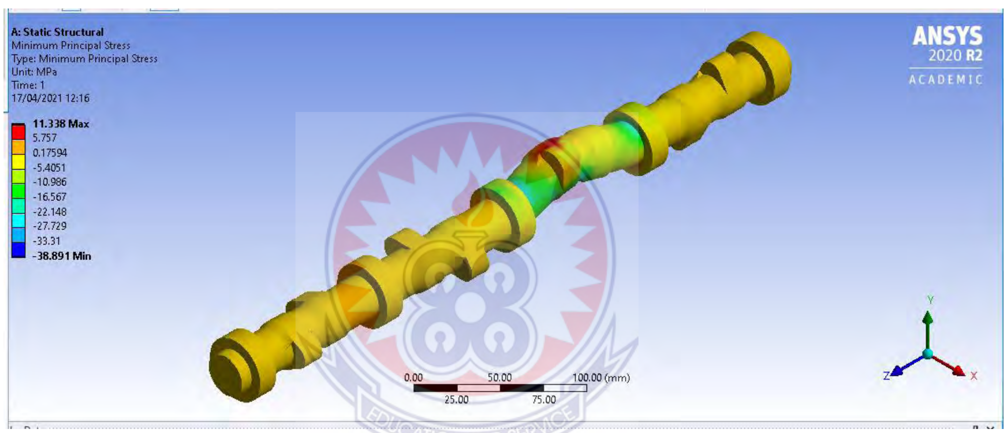

Figure 13: Minimum Principal Stress of Chilled Grey Cast Iron

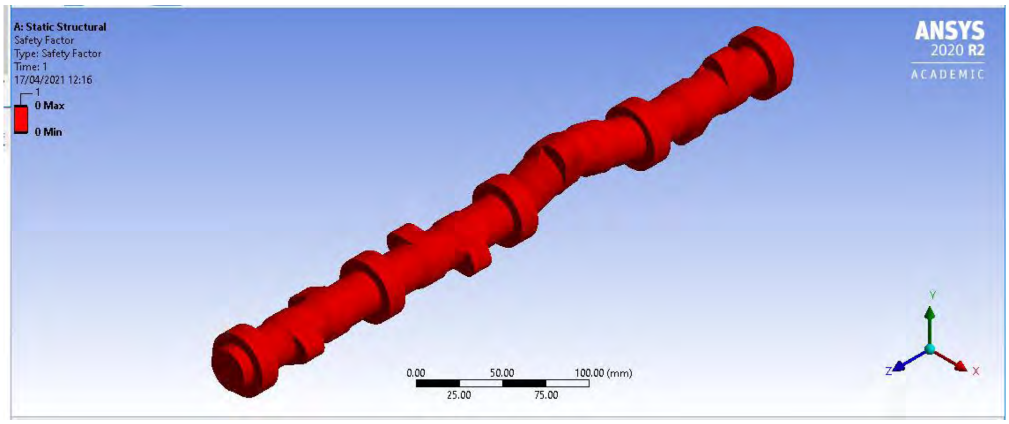

Figure 14: **Safety Factor of Chilled Grey Cast Iron**

Figure 14 shows a simulation results of chilled gray cast iron. This has a low tensile strengths and almost nonexistent ductilities (and impact strengths) due primarily to the nearly continuous nature (breaks at cell boundaries) of the graphite flakes which results in low safety factor.

Figure 8 to 14 presents the static analysis of chilled grey cast iron camshaft of a 4-stroke multi-cylinder IC engine at a load of 6588.7 N. The total deformation (maximum) was calculated using the ANSYS software. Maximum value of total deformation was 0.025321 mm with 47.292 Mpa stress value. From the analysis the equivalent (Von Mises) stress in camshaft was 47.292 MPa maximum and minimum value was 0.00039564 MPa which is shown in fig 11 and highlighted by red color. The intensity of the principal stresses in the camshaft was increased and its maximum value was 56.125 MPa and the minimum value =10.647 MPa. It is seen that the static stress values are lower than the yield point values of chilled grey cast iron. The stress analysis of the camshaft is carried out for the determination of the stress concentration level in the camshaft by the finite element method. Red colour zone indicates the maximum values of total deformation, equivalent elastic strain, equivalent (Von Mises) stress, maximum principal stress and minimum principal stress. Table 4 below shows the simulation results of chilled grey cast iron. This indicates that chilled grey cast iron deforms comparatively less as compared to aluminium 6061 t6 and higher than structural steel.

Table 4: Simulation Results for Chilled Grey Cast Iron

Material		Total Deformation	Equivalent Elastic Strain	Equivalent (Von Mises) Stress	Maximum Principal Stress
Chilled Grey Cast iron	Max	0.02532mm	0.00046613	47.292Mpa	56.126 MPa

Figure 15 to 21 shows the total deformation, equivalent elastic strain, equivalent (Von Mises) stress, maximum principal stress and minimum principal stress of structural steel camshaft.

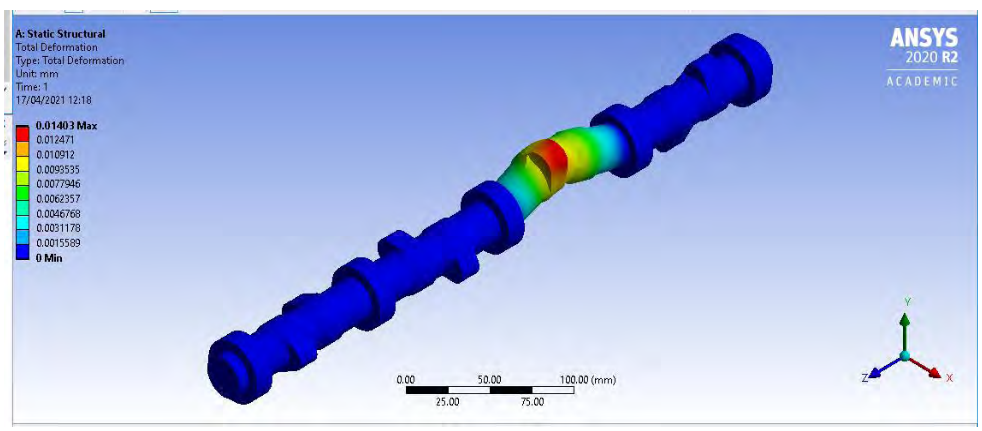

Figure 15: Total Deformation of Structural Steel

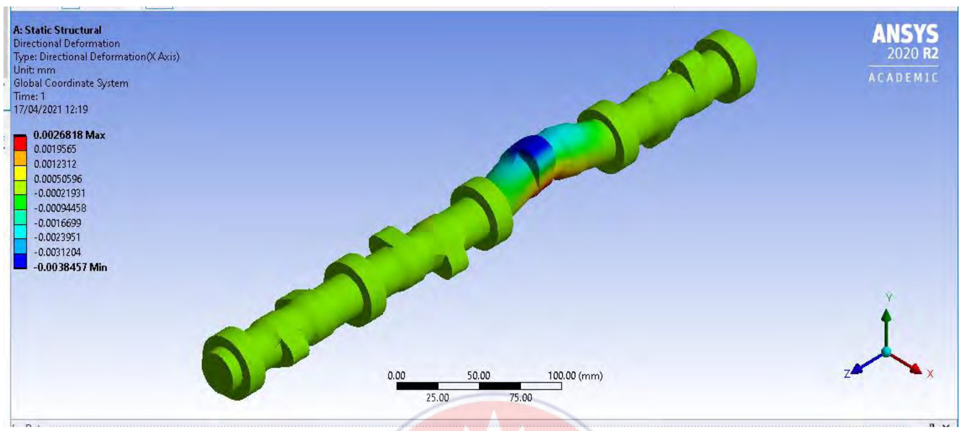

Figure 16: Directional Deformation of Structural Steel

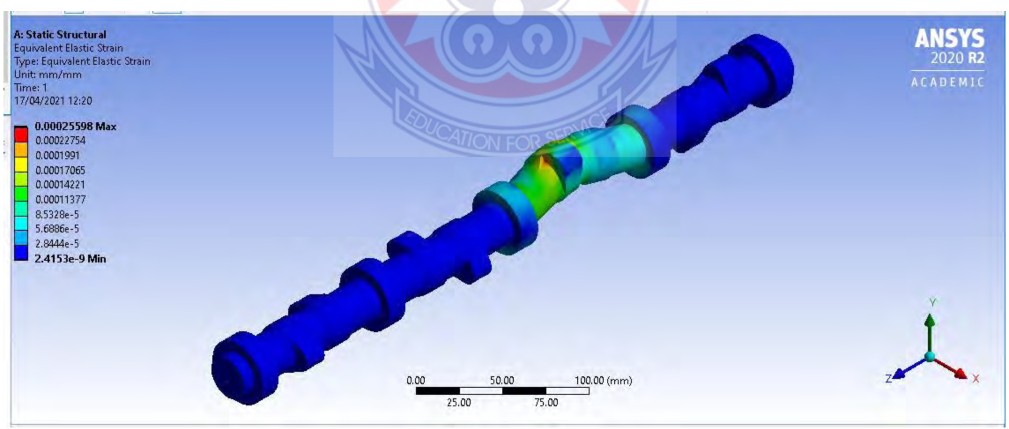

Figure 17: Equivalent Elastic Strain of Structural Steel

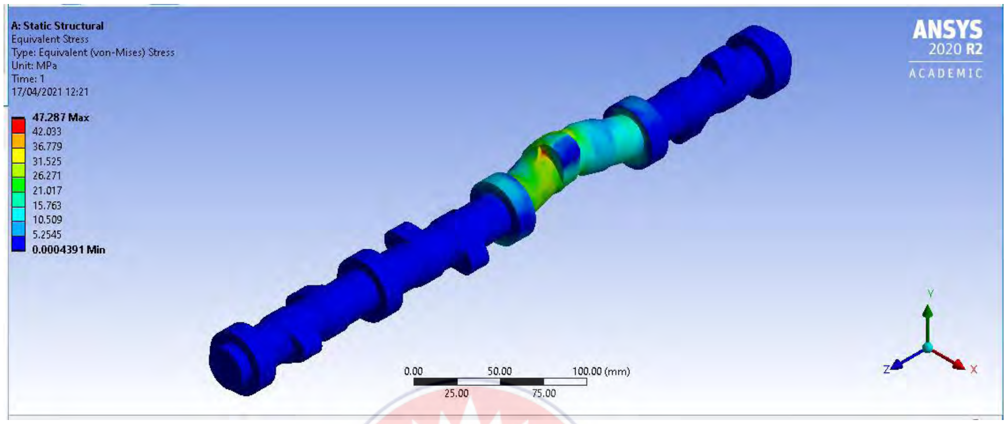

Figure 18: Equivalent (Von Mises) Stress of Structural Steel

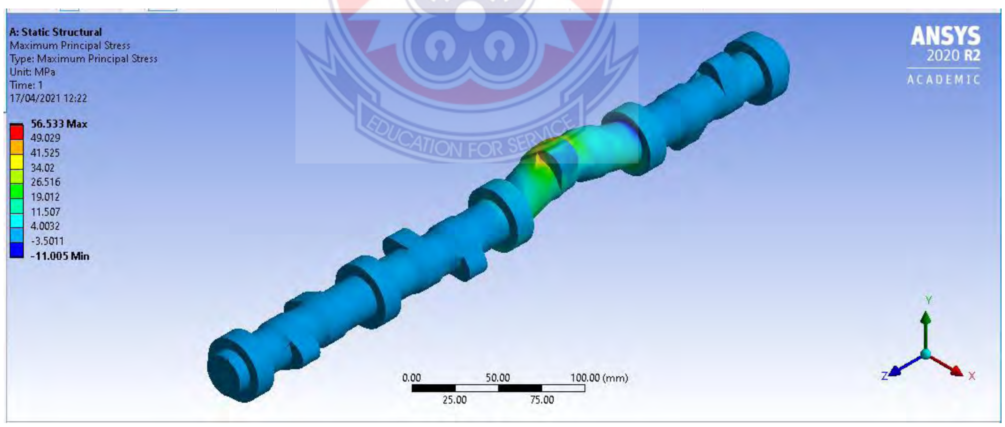

Figure 19: Maximum Principal Stress of Structural Steel

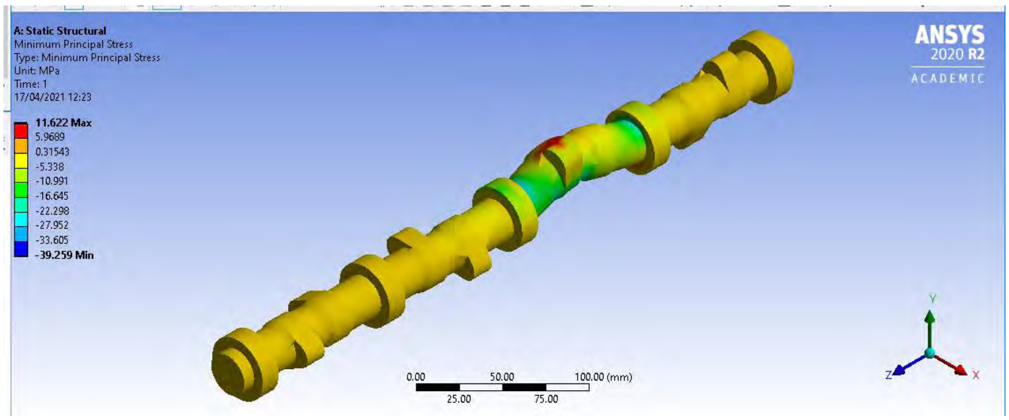

Figure 20: Minimum Principal Stress of Structural Steel

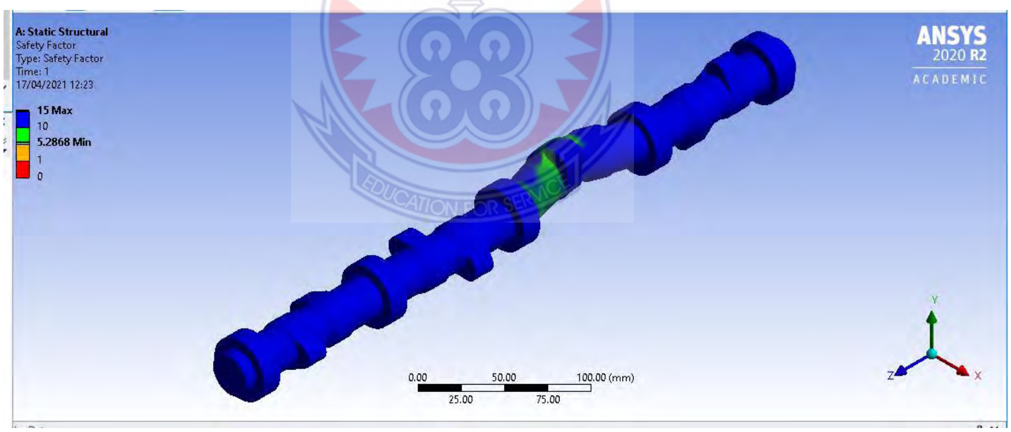

Figure 21: Safety Factor of Structural Steel

For Structural Steel, the total deformation is less although it has higher value of stress. The distribution of the equivalent stress of the engine camshaft, as shown in Fig. 15, the maximum stress (high stress zone) occurs on the lope of the camshaft. The maximum stress was 47.289 MPa, which is less than the yield strength of the material itself. Therefore, the material is considered safe for static strength.

Table 5: Results for Structural Steel material

Material		Total Deformation	Equivalent Elastic Strain	Equivalent (Von Mises) Stress	Maximum Principal Stress
Structural Steel	Max	0. 01403mm	0.00025598	47.289MPa	56.533MPa

Figure 22 to 28 shows static analysis results on total deformation, equivalent elastic Strain, equivalent (Von Mises) stress etc. of Aluminium 6061 t6 camshaft.

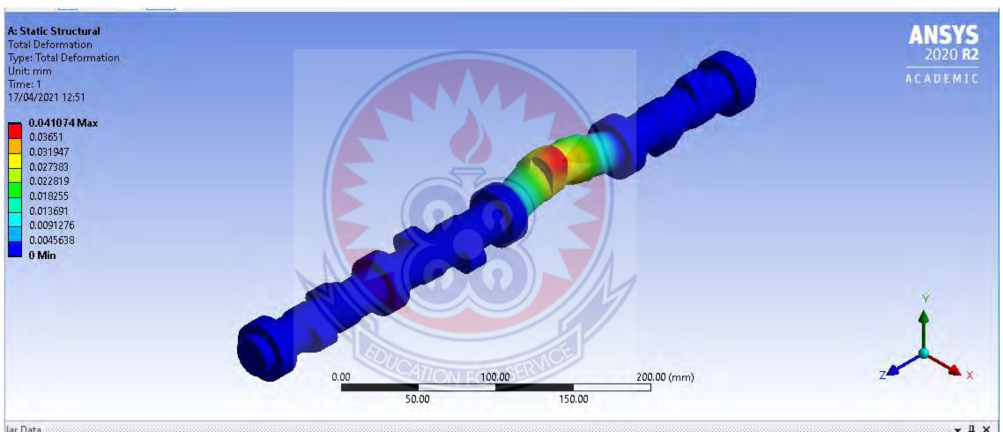

Figure 22: Total Deformation of Aluminium 6061 t6

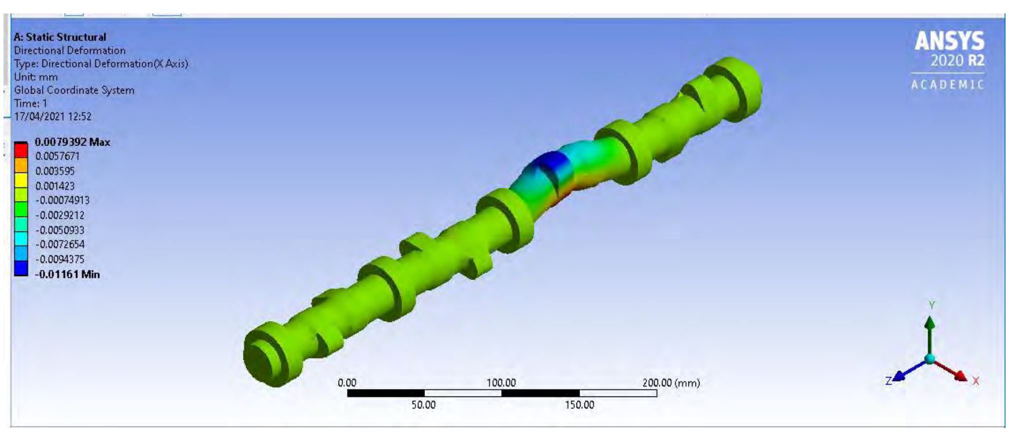

Figure 23: Directional Deformation of Aluminium 6061 t6

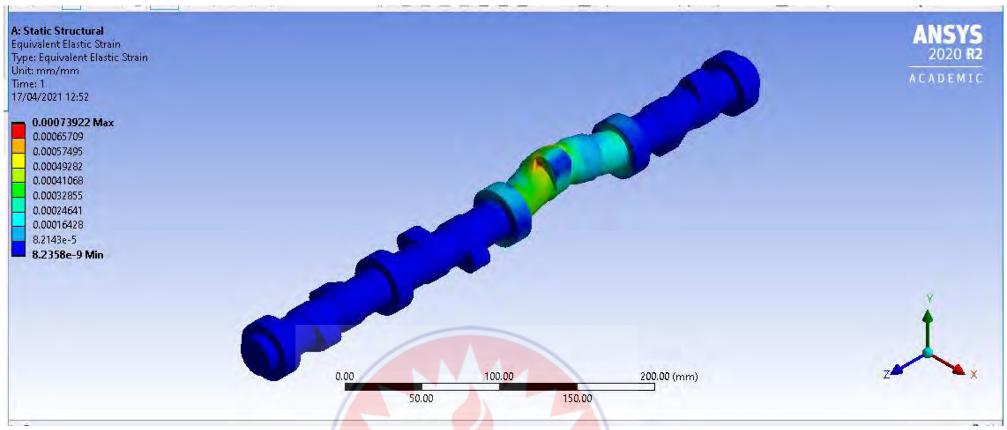

Figure 24: Equivalent Elastic Strain of Aluminium Alloy 6061 t6

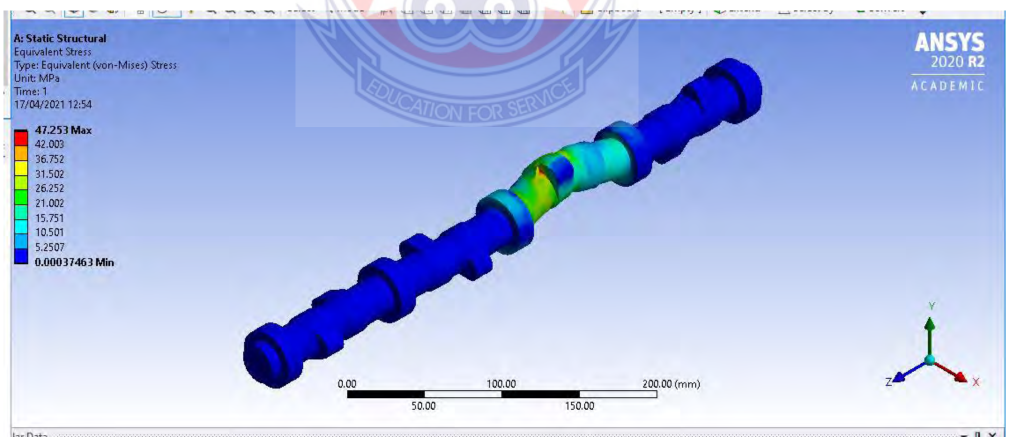

Figure 25: Equivalent (Von Mises) Stress of Aluminium Alloy 6061 t6

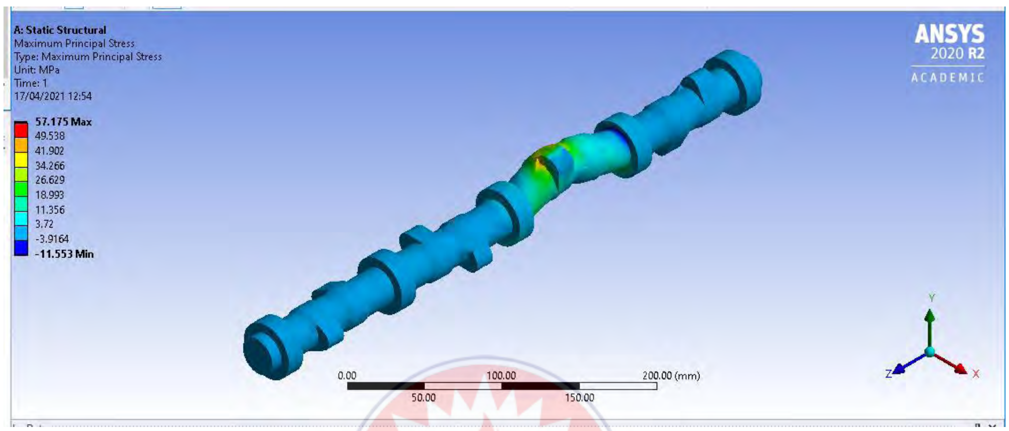

Figure 26: Maximum Principal Stress of Aluminium Alloy 6061 t6

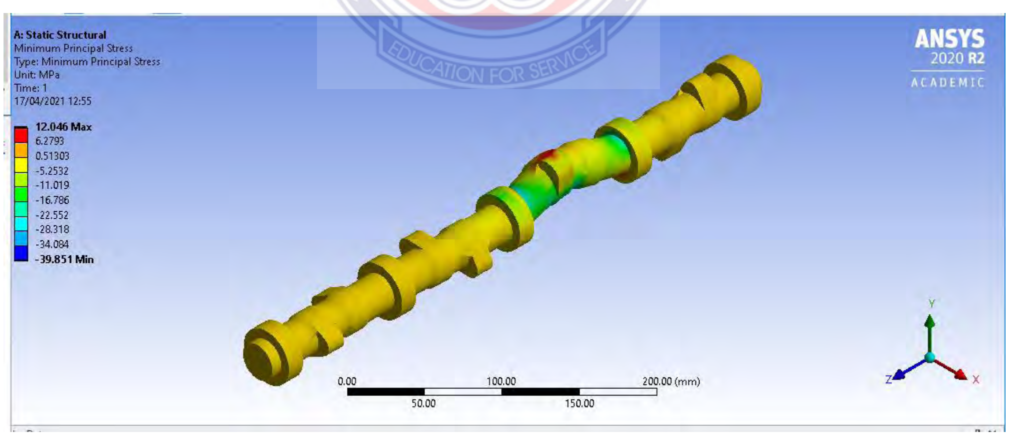

Figure 27: Minimum Principal Stress of Aluminium Alloy 6061 t6

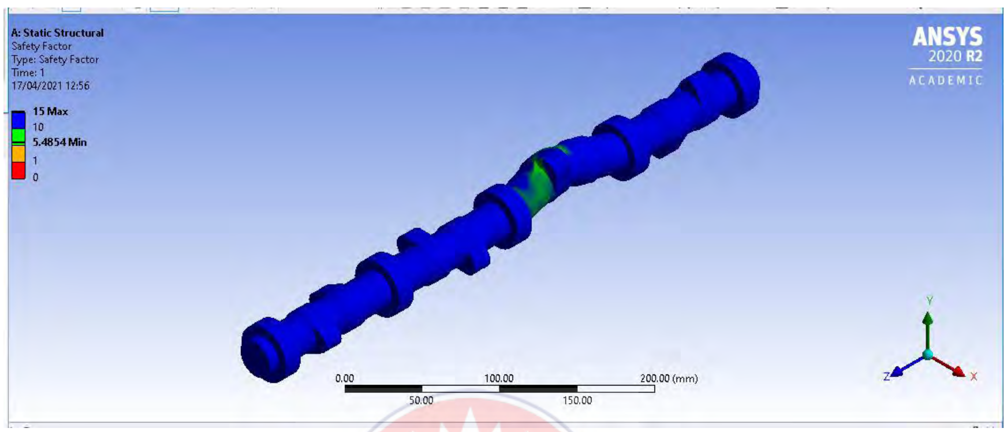

Figure 28: Safety Factor of Aluminium Alloy 6061 t6

The static analysis of aluminium 6061 t6 camshaft shows that, the equivalent (Von Mises) Stress is less than the value that has obtained from both chilled grey cast iron and structural steel but the value of total deformation in the camshaft is greater than both chilled grey cast iron and structural steel shown in Figure 23. Therefore, the factor of safety for aluminium 6061 t6 was calculated which came out to be higher. It means this material can give a long life in operating conditions, in comparison to chilled grey cast iron and structural steel. This indicates changes from chilled grey cast iron and structural steel to aluminium 6061 t6 which results in low frictional losses due to low weight which results in improved in mechanical efficiency of internal combustion engine.

Table 6: Results for Aluminium 6061 t6 material

Material	Total Deformation	Equivalent Elastic Strain	Equivalent (Von Mises) Stress	Maximum Principal Stress

Aluminium 6061 t6	Max	0.041073mm	0.00073922	47.253Mpa	57.175Mpa

4.2.1 Discussions

Table 7 below display simulated results of two existing camshaft materials namely chilled grey cast iron and structural steel and one implementing material i.e., aluminium 6061 t6 for the design of a camshaft for four-cylinder IC engine. The equivalent (Von Mises) stress and strain, maximum principal stresses in various materials have been calculated with total deformation for each material and the comparison is done for the selection of the best material. The focus here is in the performance of the engine so for two materials the value of maximum principal stress has come out to be the same i.e., 56Mpa and the third one is also a little offset by 1Mpa i.e., chilled grey cast iron. The strain value in chilled grey cast iron and structural steel are the lowest one compared to aluminium 6061 t6which is close and at the same time deformation in both materials are less. But since the weight of cast iron and structural steel is very high than the weight of aluminium 6061 it can't compensate the factor of performance of the engine over weight. So, a little compromization with deformation can be done to gain the total performance of the engine. Equivalent (Von Mises) stress of aluminium 6061 t6 is less (Figure 30) than the value that has obtained from both structural steel and chilled grey cast iron but the factor of safety for both structural steel and aluminium 6061 t6 are the same which came out to be higher because of low value of stress. It means aluminium 6061 t6 can give a long life in operating conditions, in comparison to chilled grey cast iron and structural steel. aluminium 6061 t6 is suggested as a possible alternative material for camshaft because it will provide high strength to weight ratio. The coefficient of thermal expansion is also very low. The various properties of cams, namely, high strength to weight ratio, stiffness, corrosion resistance, wear resistance, closer dimensional tolerance and versatility to designer can be measured and their variation with reinforcement content can be improved.

Table 7: Simulated Results of the Three Camshaft Materials

Material		Total Deformation	Equivalent Elastic Strain	Equivalent (Von Mises) Stress	Maximum Principal Stress
Chilled grey cast iron	Max	0.02532mm	0.00046613	47.292Mpa	56.126 MPa
Structural Steel	Max	0. 01403mm	0.00025598	47.289MPa	56.533MPa
Aluminium 6061 t6	Max	0.041073mm	0.00073922	47.253 Mpa	57.175Mpa

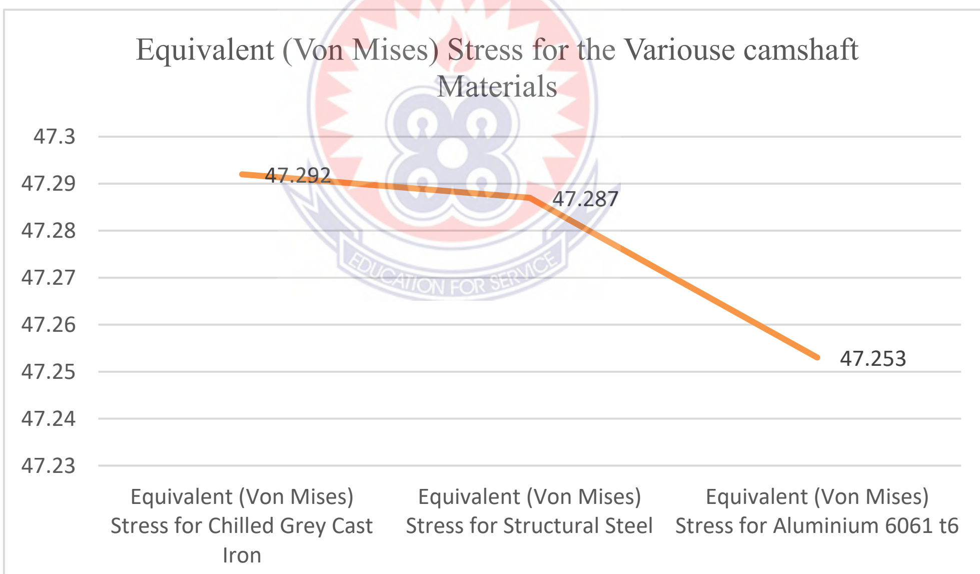

Figure 29: Equivalent (Von Mises) Stress for the Various camshaft Materials

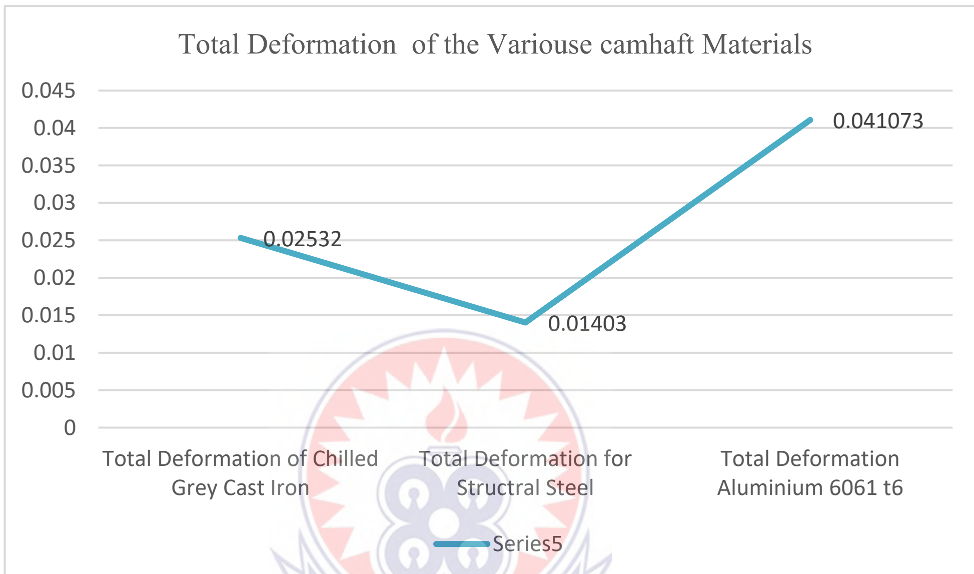

Figure 30: Total Deformation of the Various camshaft Materials

4.3 Modal Analysis

Modal analysis of the camshaft means the free vibration analysis of camshaft in which the total deformation and natural frequency of the camshaft were calculated. The total deformation and natural frequency of the various camshaft materials were calculated with the help of the ANSYS software and compared with each other that's the existing and implementing materials. First, 3D model of the camshaft was prepared in an Autodesk Inventor with exact dimension of a 4-cylinder SI engine camshaft. Then the model was imported to the ANSYS software using the given neutral file formats. Modal analysis helps to determine the vibration characteristics (natural frequencies and mode shapes) of a mechanical structure or component, showing the movement of different parts of the structure under dynamic loading conditions, such as those due to the lateral force generated by the electrostatic actuators.

Figure 31 to 36 shows the total deformation and natural frequencies emanated from modal analysis of chilled grey cast iron.

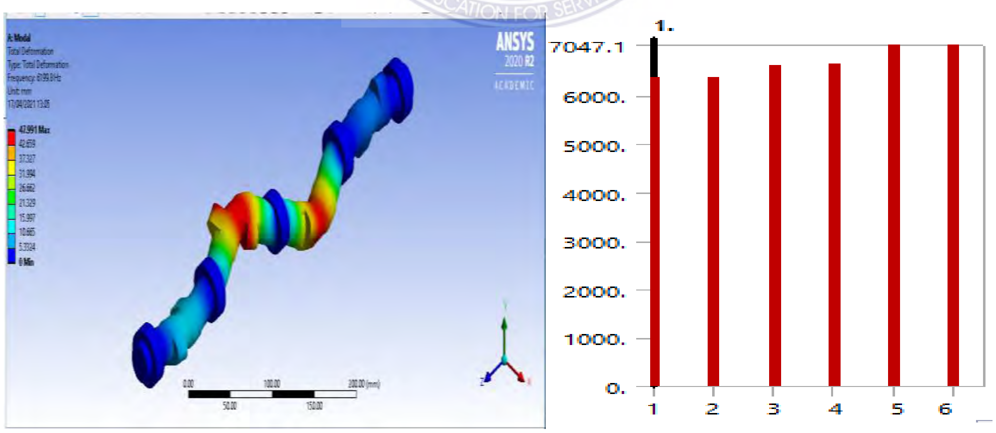

Figure 31: First Mode Shape of Chilled Grey Cast Iron Camshaft

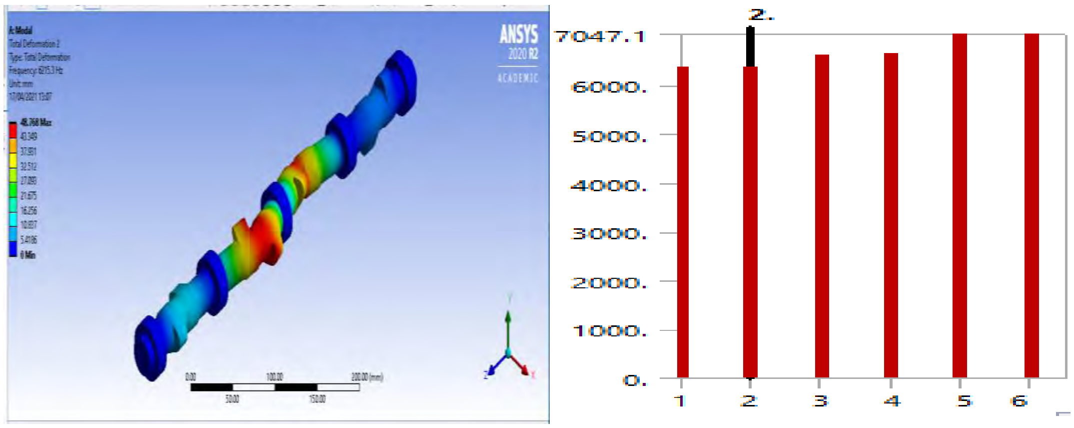

Figure 32: Second mode shape of Chilled Grey Cast Iron camshaft

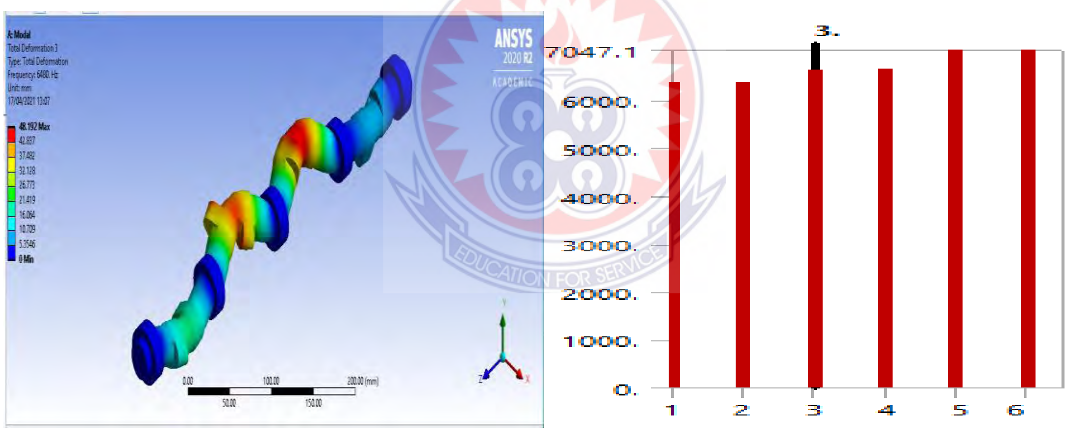

Figure 33: Third mode shape of Chilled Grey Cast Iron Camshaft

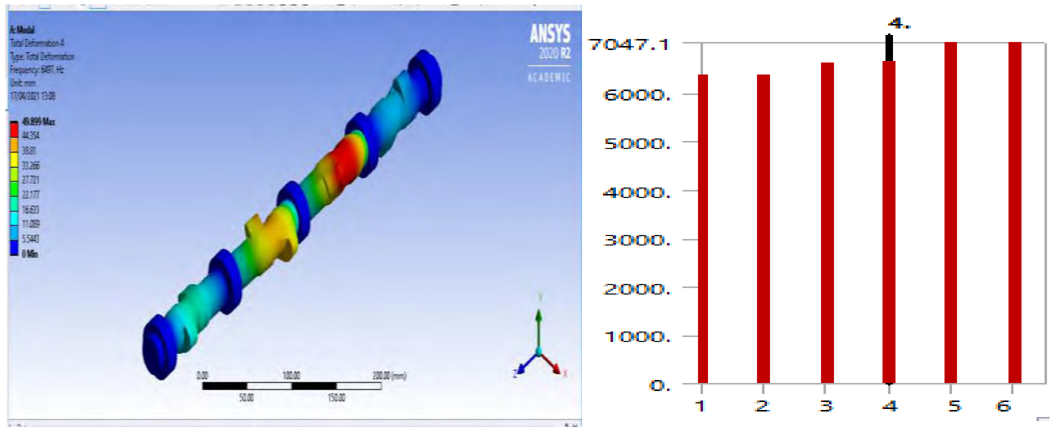

Figure 34: Forth mode shape of Chilled Grey Cast Iron Camshaft

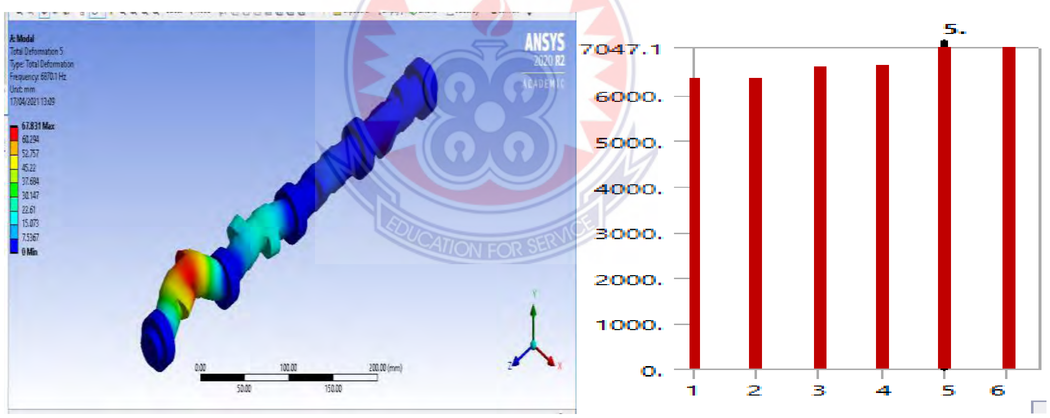

Figure 35: Fifth mode shape of Chilled Grey Cast Iron Camshaft

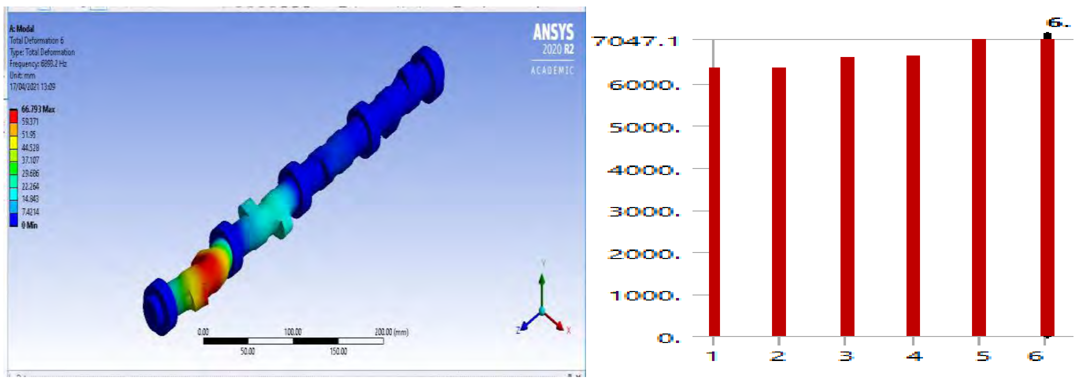

Figure 36: Sixth Mode Shape of Chilled Grey Cast Iron Camshaft

Table 8: Natural Frequencies and Deformation with Different Modes of Chilled Grey Cast Iron Camshaft

Mode	Deformation (mm)	Frequency (Hz)
1	47.991	6199.8
2	48.768	6215.3
3	48.192	6480.0
4	49.899	6497.0
5	67.831	6870.1
6	66.793	6893.2

Table 8 shows the values of frequency at different modes of the chilled grey cast iron camshaft. In the above table it is observe that, the values of frequency for the chilled grey cast iron material at six modes are less when compare to the other materials. chilled grey cast iron frequency value at mode 6 was obtained as 6893.2, mode 5 = 6870.1 etc. shown in in the graph at Figure 38. So, it is established that chilled grey cast iron having the lesser frequencies when compare with aluminium 6061 t6 and structural steel.

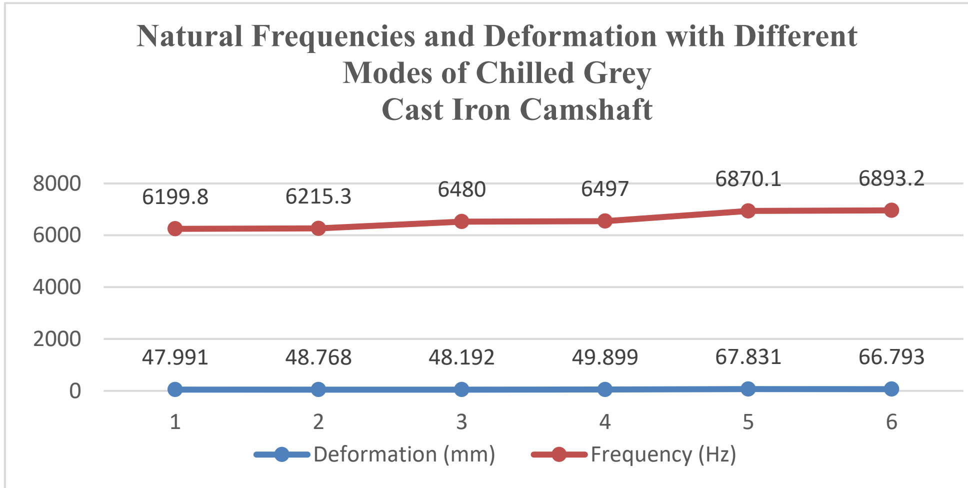

Figure 37: Natural Frequencies and Deformation with Different Modes of Chilled Grey Cast Iron Camshaft

Below shows the total deformation and natural frequencies of Structural Steel from the modal analysis. This extends from Figure 38 to 43.

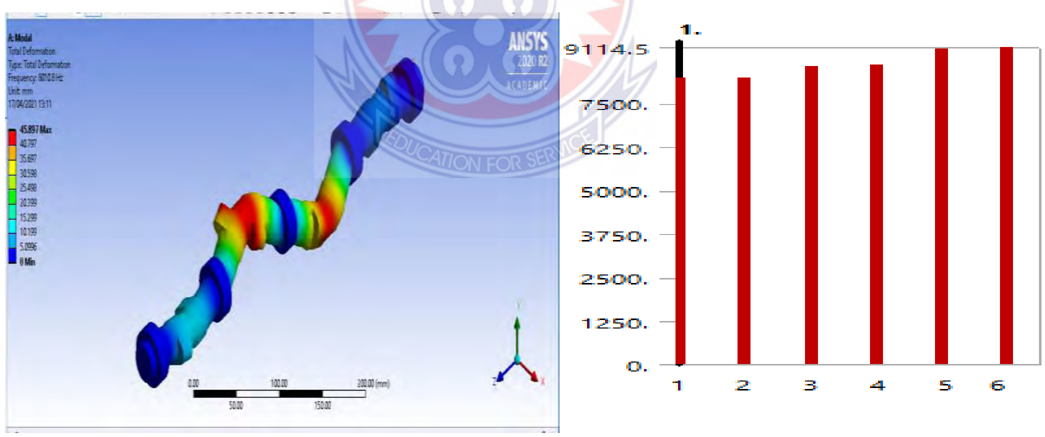

Figure 38: First Mode Shape of Structural Steel Camshaft

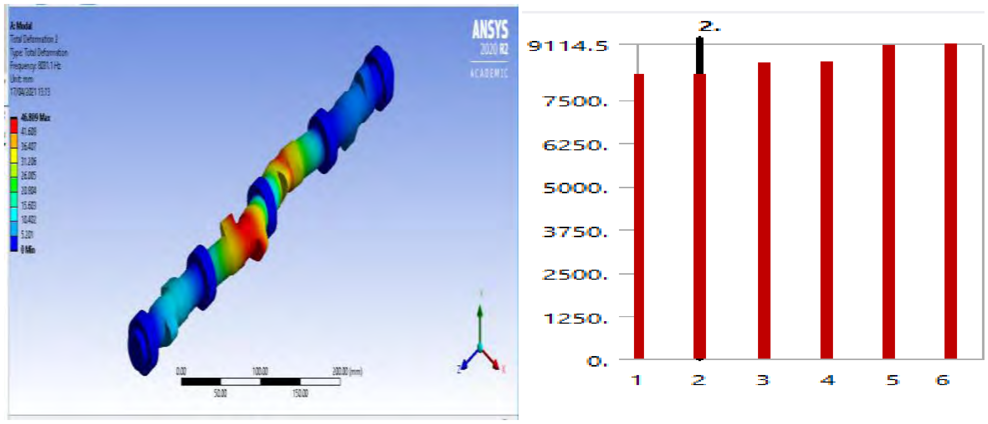

Figure 39: Second Mode Shape of Structural Steel Camshaft

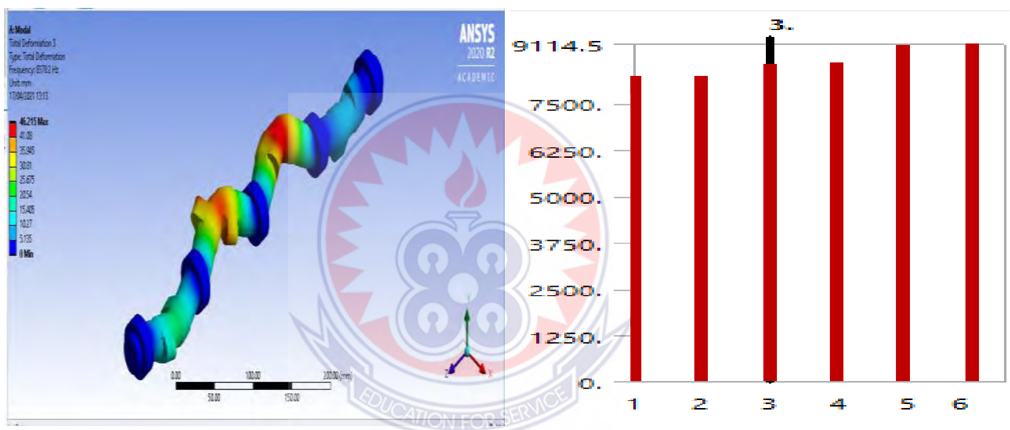

Figure 40: Third Mode Shape of Structural Steel Camshaft

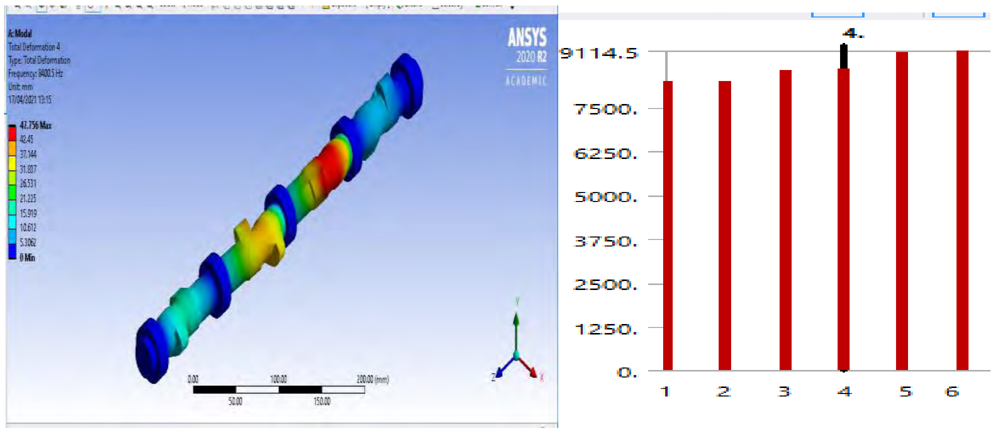

Figure 41: Forth Mode Shape of Structural Steel Camshaft

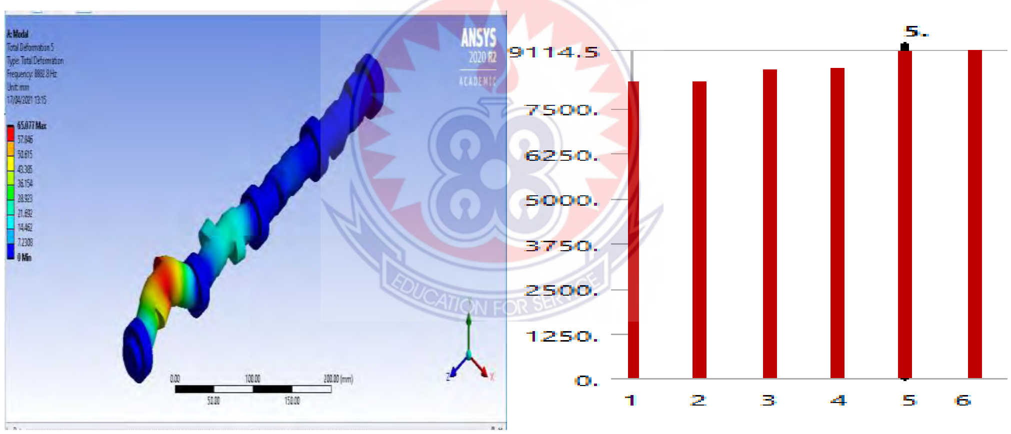

Figure 42: Fifth Mode Shape of Structural Steel Camshaft

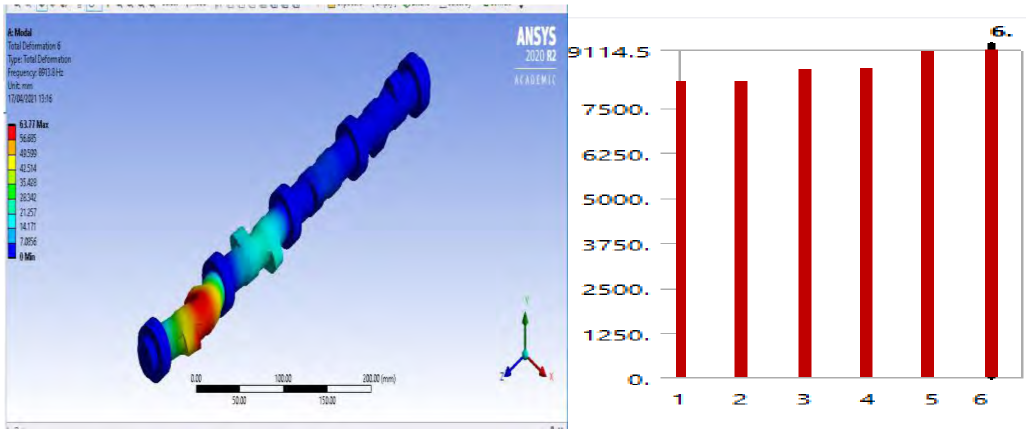

Figure 53: Sixth Mode Shape of Structural Steel Camshaft

Table 9: Natural frequencies and deformation with different modes of Structural Steel camshaft

Mode	Deformation (mm)	Frequency (Hz)
1	45.897	8010.8
2	46.809	8031.1
3	46.215	8378.2
4	47.756	8400.5
5	65.077	8882.8
6	63.77	8913.8

From Table 9, the modal frequencies for camshaft using Structural Steel are sandwich between chilled grey cast iron and aluminium 6061 t6. From the above table, it is clear that the Structural Steel camshaft deforms less when compared to Chilled Grey Cast Iron and aluminium 6061 t6.

The results from modal analysis of aluminium 6061 t6 are displayed below from Figure 45 to 50.

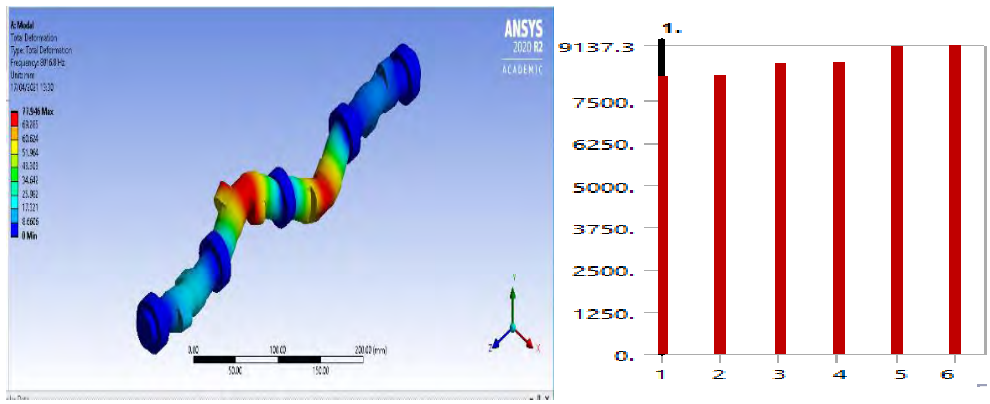

Figure 44: First Mode Shape of Aluminium 6061 t6 Camshaft

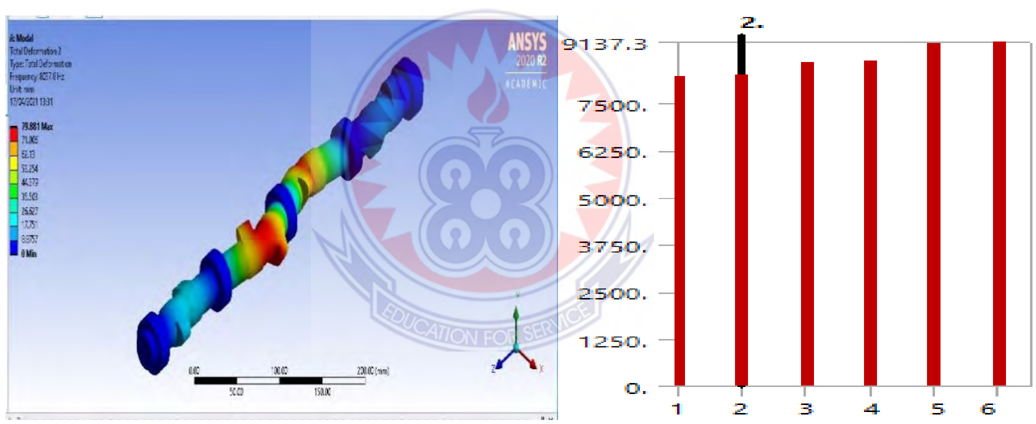

Figure 45: Second Mode Shape of Aluminium 6061 t6 Camshaft

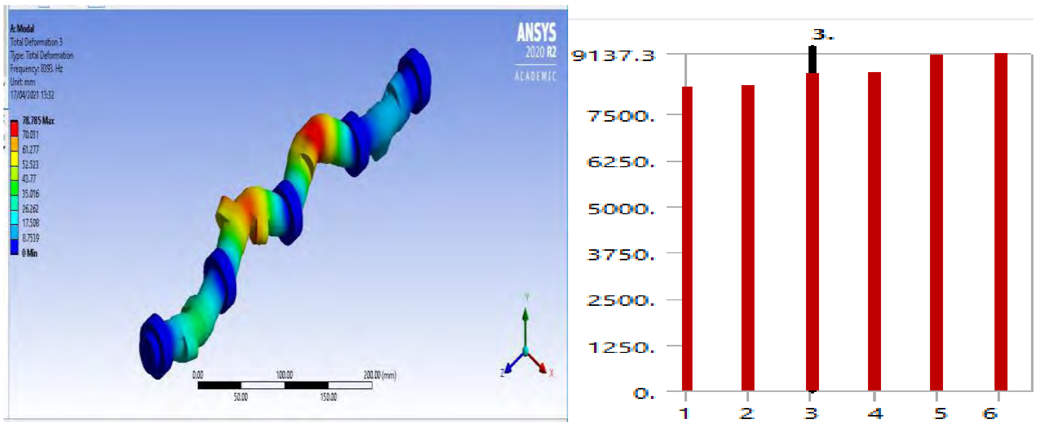

Figure 46: Third Mode Shape of Aluminium 6061 t6 Camshaft

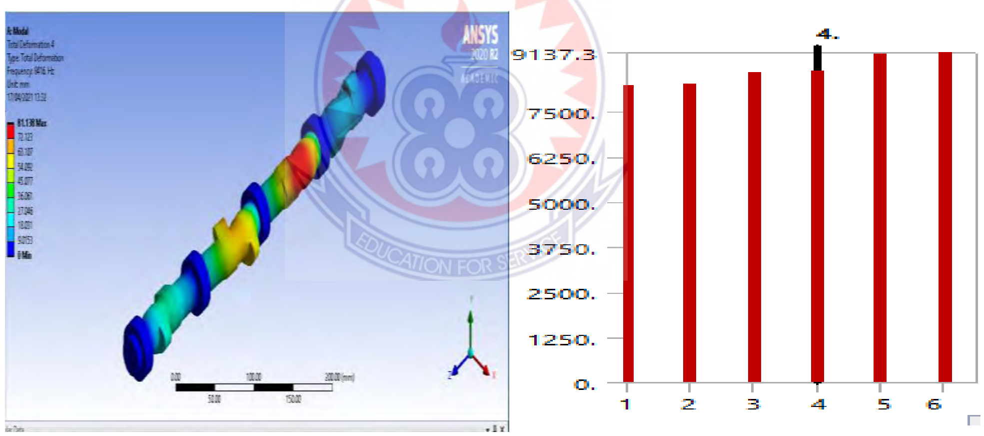

Figure 47: Forth Mode Shape of Aluminium6061 t6 Camshaft

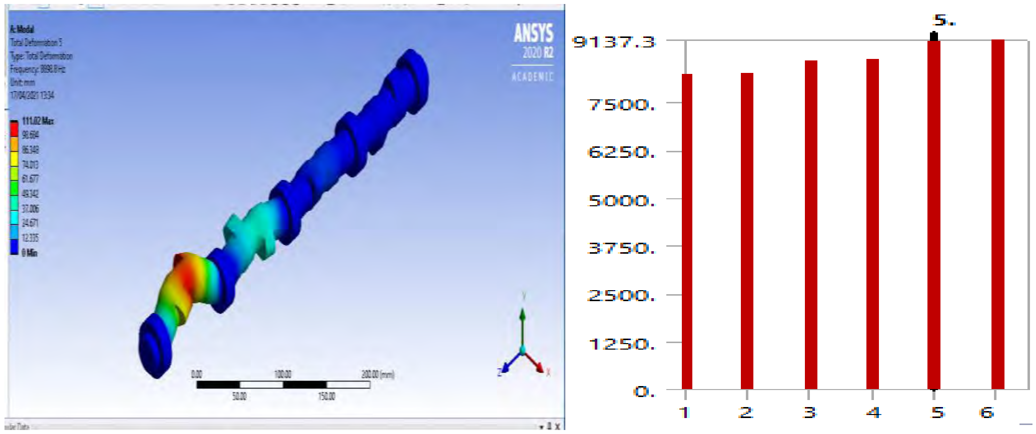

Figure 48: Fifth Mode Shape of Aluminium 6061 t6 Camshaft

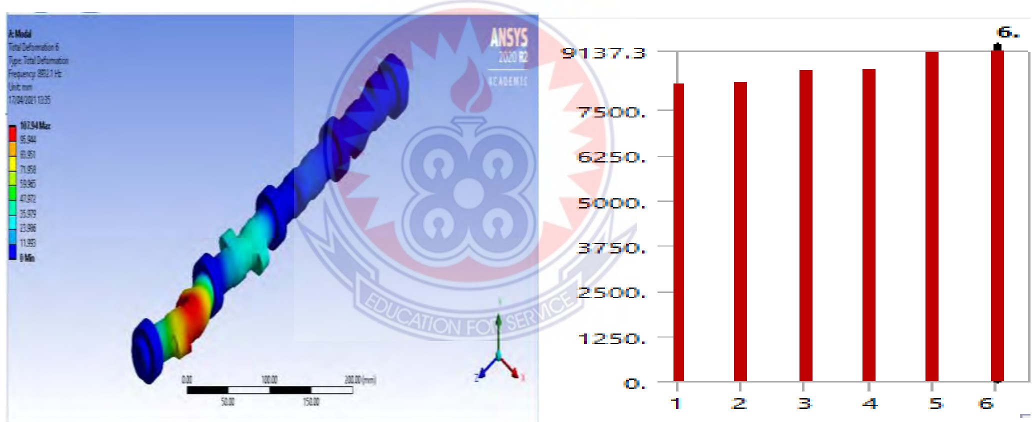

Figure 49: Sixth Mode Shape of Aluminium 6061 t6 Camshaft

Table 10: Natural Frequencies and Deformation with Different Modes of Aluminium6061 t6 Camshaft.

Mode	Deformation (mm)	Frequency (Hz)
1	77.946	8016.8
2	79.881	8037.8
3	78.785	8393.0
4	81.138	8416.0
5	111.02	8898.8
6	107.94	8932.1

By observing the modal evaluation in Table 7, the frequency values are higher for aluminium alloy 6061 t6. So, it may be stated that the aluminium alloy 6061 t6 is healthier material for the camshaft. These are shown in Figure,44 to 49.

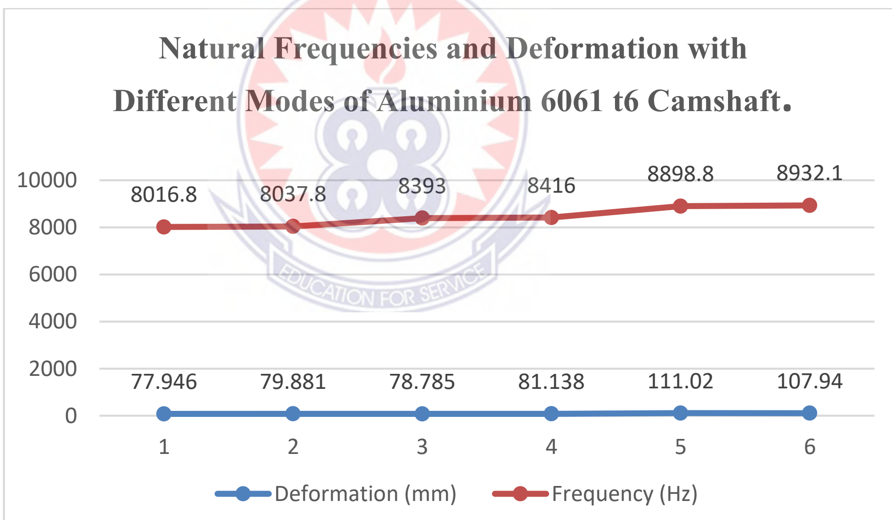

Figure 50: Natural Frequencies and Deformation of Aluminium 6061 t6 Camshaft.

Table 11: Weight of the Various Camshafts

Material	Weight
Chilled grey cast iron	24.2852436 KN
Structural steel	25.850 KN
Aluminium 6061 t6	8.86645 KN

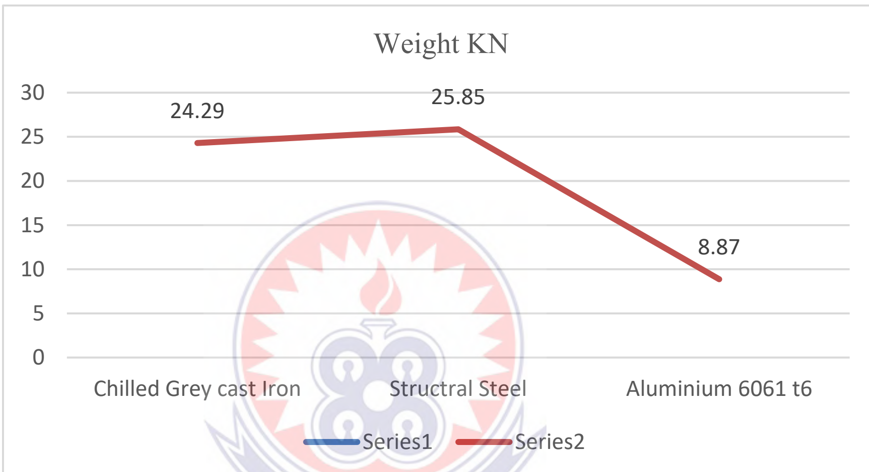

Figure 51: Weight of the Various Camshafts

Table 12: Natural Frequencies and Deformation with Different Modes of the Various Camshaft Materials

Material	Mode	Deformation(mm)	Frequency (Hz)
Chilled grey Cast Iron	1	47.991	6199.8
	2	48.768	6215.3
	3	48.192	6480.0
	4	49.899	6497.0
	5	67.831	6870.1
	6	66.793	6893.2
Structural Steel	1	45.897	8010.8
	2	46.809	8031.1
	3	46.215	8378.2
	4	47.756	8400.5
	5	65.077	8882.8
	6	63.77	8913.8
Aluminium 6061 t6	1	77.946	8016.8
	2	79.881	8037.8
	3	78.785	8393.0
	4	81.138	8416.0
	5	111.02	8898.8
	6	107.94	8932.1

4.3.1 Discussions on Modal Analysis

The modal analysis presented the natural frequencies and total deformation of the various camshaft materials at different modes for all the selected materials. Frequency range of aluminium 6061 t6 shows a very good match with the frequency range of structural steel and better than chilled grey cast iron. The obtained frequency range of existing chilled grey cast iron camshaftwas6199.8 Hz (Figure 32) to 6893.2 Hz (Figure 37), structural steel was 8010.8 to 8913.8 (Figure 39) to (Figure 44) and for modified aluminium 6061 t6 was 8016.8Hz (Figure 45) to 8932.1 Hz (Figure 50). As frequency range of modified camshaft is within the frequency range of existing camshafts, the modified design proves to be safe. The total deformation of aluminium 6061 t6 is less compared to chilled grey cast iron and the same as Structural Steel. This indicates change of the chilled grey cast iron and structural steel camshafts to aluminium 6061 t6 camshaft results in high natural frequency due to lowest weight value and the deformation close to the existing camshaft materials in the operating conditions.

4.3.2 Validation

Table 13 below shows the validated results of the study. From the results the equivalent (Von Mises) stress for the aluminium 6061 t6 camshaft was within the experimented value and the total deformation was matched with a slight margin of offset from experimented value. For chilled grey cast iron, the experimented values are close with the values from the ANSYS software.

Table 13: Validated Results

Chilled grey cast iron					
Values from the software (ANSYS)			Values from experiment		
Total Deformation	Equivalent Elastic Strain	Equivalent (Von Mises) Stress	Total Deformation	Elastic Strain	Stress
0.02532mm	0.00046613	47.292Mpa	0.02522mm	0.00045613	47.392Mpa
Aluminium 6061 t6					
0.041073mm	0.00073922	47.253 Mpa	0.042073mm	0.00064922	47.453 Mpa

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In this study, design and model analysis of camshaft was done by using Autodesk Inventor and ANSYS software. By using ANSYS the static and modal analysis was done to determine the total and directional deformation, equivalent (Von Mises) stress, maximum and minimum principal stresses, natural frequencies etc. of the various camshaft materials. The deformation and stresses were calculated using the ANSYS software. The calculation methodology presented can be applied to several types of ICEs from spark ignition to diesel engines, in-line or 'V' types, and 2 or 4-stroke engines, taking into account the correct ignition timing and sequence. The present study provides a high-performance lightweight aluminium camshaft and a manufacturing method which can enhance engine durability due to minimization of no – oil – supply wear occurring during cold start in the engine, reduction of an inertia of moment due to the lightweight camshaft, and realize enhancement of an output from an engine and also realize a high fuel efficiency through high RPM (Revolutions Per Minute) of the engine.

The results obtained from the static analysis indicate that aluminium 6061 t6 is also applicable for manufacturing of the camshaft, as the equivalent (Von-Mises) stress values of camshaft is less compared with chilled grey cast iron and structural steel. The static analysis revealed that aluminium 6061 t6 is appropriate for the fabrication of the camshaft as it may be cost effective. Aluminium 6061 t6 is suggested as a possible alternative material for camshaft because it will provide high strength to weight ratio. The coefficient of thermal expansion is also low. The various properties of cams, namely, high strength to weight ratio, stiffness, corrosion resistance, wear resistance, closer dimensional tolerance and versatility to designer all geared towards enhancing performance of the engine. However, it also has some disadvantages; it has the largest total and directional deformation as compare to structural steel and chilled grey cast iron shown in Figure 50. In reflecting on the design, all objectives were successfully met. The design product engineered will help manufactures to maximize the production of the internal combustion engine camshafts with minimum cost. For another application the material selection for camshaft become easier for the manufacturers.

The modal analysis revealed the natural frequencies and total deformation of the various materials at different modes for all the selected materials. In the study, it is observed that, the values of natural frequency for the aluminium 6061 t6 material at different modes are higher than the existing materials. The total deformation of aluminium 6061 t6 is less compared to chilled grey cast iron and the same as structural steel.

After analysing the various materials, it reveals that the material which is having the lowest weight is having the highest value of deformation and the material that have the lowest deformation have the highest weight shown in Table 12. So, the material selected from the given data is aluminium 6061 t6 which is having the lower weight value and the deformation close to the existing camshaft materials in the operating conditions. Finally, it can be concluded that aluminium 6061 t6 material is best suited for 4-cylinder camshafts for spark ignition engine.

5.2 Conclusions

The design and development of the camshaft has been an iterative process that relies on individual experience and skill. During the present study, an alternative approach has been considered; to select the key features of a concept design, to describe them in terms of defined parameters and to understand how they influence camshaft performance characteristics. In doing so, the interactions between those design features and external constraints have been considered. The result is clearly a simplified model of the fully developed and manufactured prototype. However, one of the most important aspects of concept design is to compare the new design with the existing camshafts. The results shows that the performance models are robust and sufficiently well developed to provide reliable camshaft. General trends such as lightweight are evident in the analysis of summary performance characteristics. Easily understood parameter responses, such as the Von Mesis Stress demonstrate that the model camshaft was consistent with the findings of other researchers.

5.3 Recommendations

1. It is recommended that car manufacturers should consider composite camshafts because castings made, resulting from cast iron require extensive reworking after casting in high costs. aluminium 6061 t6 allow a near-net-shape manufacturing, thus requiring comparatively little reworking and which again leads to reduced production cost.

2. Also aluminium 6061 t6 camshafts will be a great relief to automotive manufacturers as they are eager to minimize weight. Heavy cars are not only annoying, they are also a clear competitive disadvantage, so weight, characteristics are high up on the list of factors used to assess vehicle quality. lightweight cars have good fuel economy and also reduces assembly costs.

3. It is further recommended that, vehicle manufacturers use aluminium 6061 t6 camshafts because the module features a monolithic design – in other words, it is casted in one piece, thus reducing assembly time in the engine manufacturing plant. Car manufacturers receive a pre-assembled module from their supplier and can mount it on the engine with just a few simple mounting operations. This eliminates the need for separate, time-consuming installation of the camshaft. This innovative solution boasts an additional advantage.

5.4 Future Work

It is suggested that further research be carried out on other composite materials since this study was limited to only aluminium 6061 t6. Again, where applicable and appropriate, further exploitation of composite models could be used to optimised performance at specific valve lift conditions, or to investigate variable valve-lift strategies. Investigation of multi- camshaft design configurations, including alternatives such as siamese valves should also be undertaken. Also, further changes can be made in the design considering into mind the reduction of weight of the camshaft i.e., work towards the weight minimization. The analysis can be done with change in material of camshaft can be changed for better strength and light weight. However, further development of the models would provide enhanced performance capabilities and a greater understanding of engine and camshaft performance characteristics. New performance models for camshafts used with Compression Ignition Engines (CIE) could be developed using similar technique. Also, the prototype camshaft can be developed to be tested in a real vehicle.

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