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"Study of Modeling and Fracture Analysis of Camshaft" A Review.

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Abstract

Camshaft is used in the engine for transfers' motion to inlet & exhaust valve. If transfer of motion is not proper then the strokes of the engine will not done in proper way. It also effects on performance of engine. To make work of camshaft in precise way, it is require in order to design a good mechanism linkage of camshaft. To design good mechanism linkages the dynamic behavior of the components must be considered, this includes the mathematical behavior of physical model . In this case, introduction of two mass, single degree of freedom and multiple degree of freedom dynamic models of cam follower systems are studied.

In four strokes engine one of the most important component is camshaft, such a important part and that over the years subject of extensive research. In this study, causes of fracture of camshaft are discuses. By using scanning electron microscopy and finite element analysis methods are used for fracture analysis of camshaft.

Key Words: Camshaft, Fracture analysis, Stress analysis, Dynamic models.

1. Introduction

Camshaft is used in the engine for transfers motion to inlet & exhaust valve. If transfer of motion is not proper then the stokes will not work in proper way. Also it effects on performance of engine. To make work of camshaft in precise way. It is required in order to design a good mechanism linkage, the dynamic behavior of the components must be considered; This includes the gross kinematic motion and self-induced vibration motion. Dynamic models were created to obtain insight into dynamic behavior of the system prior to manufacturing. These models were mathematical tools used to simulate and predict the behavior of physical systems. They contain systems properties which are masses, stiffness constants, and damping coefficients.

The automotive sector has reached a very high production capacity in the last decades. Depending on this increasing capacity, its stable growth is anticipated in the world economy. The economic value of the work capacity in the automotive sector is very large and this shows that the automotive sector is the 6th economic sector worldwide. The sector has an interrelationship with more than 300 different fields. So, if there is any malfunction in the main or side industries, the whole functions of the produced cars are influenced. On the other hand, the failure analysis is a special field of study for materials and mechanical engineers. On one side, the materials engineer is intended to develop his/her observational and reasoning skills for the understanding of interrelationship between observable features and properties or performance. On the other side, the mechanical engineer studies on the possible failure locations and types and amount of the existent stress levels. Many studies have been carried out on the automotive failure analysis is that the mostly failed parts are from engine and its components among the automotive failures. This is followed by the drive train failures. Among the studies on the engine component failures, the prediction of fatigue failure in a camshaft using the crack-modeling method.

2. MATERIAL PROPERTIES OF THE CAMSHAFT

Chemical analysis of camshaft material is carried out by using Spectrometer, chemical analysis process is to know about camshaft material, its chemical composition and properties of camshaft material.

2.1 Material properties of the camshaft:

Chemical analysis of the fractured camshaft material was carried out using a spectrometer. The chemical composition of the material is given in Table 1. Chemical composition shows that the material is a nodular graphite cast iron. This material has good fluidity and castability, excellent machinability, and good wear resistance. In addition, nodular graphite cast iron has a number of properties similar to those of steel such as high strength, toughness, ductility, hot workability, and hardenability.

The carbon content of unalloyed ductile iron ranges from 3.0% to 4.0% C and the silicon content from 1.8% to 2.8%. The sulfur and phosphorus levels of high-quality ductile iron must be kept very low at 0.03% for S and 0.1% for P. Other impurity elements also must be kept low because they interfere with the formation of graphite nodules in ductile cast iron. The spherical nodules in ductile cast iron are formed during the solidification of the molten iron, because the sulfur and oxygen levels in the iron are reduced to very low levels by adding magnesium to the metal just before it is cast. The magnesium reacts with sulfur and oxygen so that these elements cannot interfere with the formation of the spherical-like nodules.

The average hardness of the cross-section is obtained as 23.1 HRC while the average surface hardness values of heat treated regions are obtained as 56.1 HRC. The mechanical properties for the nodular cast iron having similar chemical composition and microstructure are given approximately as 450 MPa for yield strength and 550 MPa for ultimate strength. Some metallographic studies are carried out to determine the microstructure. As can be seen, there is a good nodularity of the graphite in a ferritic–pearlitic matrix structure. Chemical analysis of the camshaft material.[1]

Table 1. Chemical Composition of Material [1]

Composition (wt %)	
Fe	Balance
C	3.42
Si	2.33
Mn	0.296
Mo	0.010
Ni	0.038
Al	0.010
Cu	0.518
Ti	0.028
Mg	0.026
S	0.009
P	0

In next chapter discussion of fracture analysis, fracture mechanics, fracture strength is carried out and also discuss about types of fractures & crack separation of modes of material.

3. FRACTURE ANALYSIS

Fracture is separation of an object in to two or more pieces under the action of stress. Fracture reduces strength of an object, to study the fracture analysis study of fracture mechanics, fracture strength, types of fractures is important. Crack separation modes study is required to know about behavior of separation of material.

3.1 Fracture analysis:

Fracture analysis is an important process in many branches of manufacturing, such as the electronics, medical, aerospace industries, where it is a vital tool used to determine the cause of a failure in order to keep it from recurring.

- Failure Analysis of Electronic Devices
- Failure Analysis of Medical Devices
- Failure Analysis of Ceramics and Plastics
- Metallurgical Failure Analysis
- A fracture is the local separation of an object or material into two, or more, pieces under the action of stress.
- The word fracture is often applied to bones of living creatures, or to crystals or crystalline materials, such as gemstones or metal. Sometimes, in crystalline materials, individual crystals fracture without the body actually separating into two or more pieces. Depending on the substance which is fractured, a fracture reduces strength or inhibits transmission of light. A detailed understanding of how fracture occurs in materials may be assisted by the study of fracture mechanics.[3]

3.2 Fracture mechanics:

Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. Fracture mechanics is an important tool in improving the mechanical performance of materials and components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity.[3]

3.3. Fracture strength:

Fracture strength, also known as breaking strength, is the stress at which a specimen fails via fracture. This is usually determined for a given specimen by a tensile test, which charts the stress-strain curve. The final recorded point is the fracture strength.

Ductile materials have fracture strength lower than the ultimate tensile strength where as in brittle materials the fracture strength is equivalent to the ultimate tensile strength. If a ductile material reaches its ultimate tensile strength in a load-controlled situation, it will continue to deform, with no additional load application, until it ruptures. However, if the loading is displacement-controlled, the deformation of the material may relieve the load, preventing rupture. [3]

3.4. Types of fractures:

3.4.1 Brittle fracture:

Figure 3.4.1 a) Brittle fracture in glass [3]

Figure 3.4.1 b) Fracture of an Aluminum Crank Arm [3]

Fracture of an Aluminum Crank Arm. As shown in pictures there are two different shades one is bright and other is dark. The bright shade indicates brittle fracture and dark shade indicates fatigue fracture.

In brittle fracture, no apparent plastic deformation takes place before fracture. In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding In amorphous solids, by contrast, the lack of a crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension. [3]

3.4.2 Ductile fracture:

Figure 3.4.2 Ductile fracture [3]

In ductile fracture, extensive plastic deformation takes place before fracture. The terms rupture or ductile rupture describes the ultimate failure of tough ductile materials loaded in tension. Rather than cracking, the material "pulls apart," generally leaving a rough surface. In this case there is slow propagation and absorption of large amount energy before fracture.

Many ductile metals, especially materials with high purity, can sustain very large deformation of 50–100% or more strain before fracture under favorable loading condition and environmental condition. The strain at which the fracture happens is controlled by the purity of the materials. At room temperature, pure iron can undergo deformation up to 100% strain before breaking, while cast iron or high-carbon steels can barely sustain 3% of strain.

Because ductile rupture involves a high degree of plastic deformation, the fracture behavior of a propagating crack as modeled above changes fundamentally. Some of the energy from stress concentrations at the crack tips is dissipated by plastic deformation before the crack actually propagates. The basic steps sample of smallest cross-sectional area, void formation, void coalescence (also known as crack formation), crack propagation, and failure, often resulting in a cup-and-cone shaped failure surface. [3]

3.4. Crack separation modes:

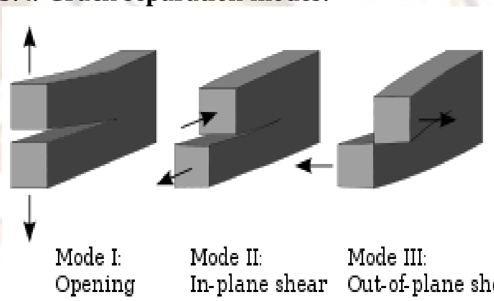


Figure 3.4. Crack separation modes [3]

There are three ways of applying a force to enable a crack to propagate:

- **Mode I crack** – Opening mode (a tensile stress normal to the plane of the crack)
- **Mode II crack** – Sliding mode (a shear stress acting parallel to the plane of the crack and perpendicular to the crack front)
- **Mode III crack** – Tearing mode (a shear stress acting parallel to the plane of the crack and parallel to the crack front) [3]

In the next chapter is discussion of different methods of fracture analysis is carried out to study about methods of fracture analysis.

4. METHODS OF FRACTURE ANALYSIS

To study fracture analysis of camshaft, there are different methods by which fracture analysis can be studied, different methods means tools and techniques used to study of fracture analysis.

4.1 Methods of fracture Analysis:

The failure analysis of many different products involves the use of the following tools and techniques:

4.2 Microscope:

A microscope is an instrument to see objects too small for the naked eye. The science of investigating small objects using such an instrument is called microscopy. Microscopic means invisible to the eye unless aided by a microscope. [3]

4.3 Sample Preparation:

Sample preparation is an essential stage in the analysis process. It takes place between sample taking and measuring the prepared sample by means of X-ray spectrometry or X-ray diffraction. Depending on the type of sample, there are various ways to prepare it in such a way that the sample is ready for measurement. [3]

4.4 Spectroscopic Analysis:

Spectroscopy is the study of the interaction between matter and radiated energy, spectroscopy originated through the study of visible light dispersed according to its wavelength, e.g., by a prism. Later the concept was expanded greatly to comprise any interaction with radiative energy as a function of its wavelength or frequency. Spectroscopic data is often represented by a spectrum, a plot of the response of interest as a function of wavelength or frequency. [3]

4.5 Scanning Electron Microscopy:

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. [3]

In the next chapter study of camshaft fracture is discussed, in this camshaft fracture discussion is carried out & also discussion of techniques of experiment is carried out.

5. CASE STUDY OF CAMSHAFT FRACTURE

Camshaft is the main component in the 4 stroke engine, which is used to lift of inlet and exhaust valve. Working of camshaft is not proper then efficiency of engine is reduced. So study of camshaft fracture is important. Study of camshaft fracture is discussed with the help of two techniques of experiments 1st is scanning electron microscopy & 2nd is finite element analysis in which reason of fracture of cam shaft is find out.

5.1 Case Study of Camshaft Fracture:

The camshaft is a shaft having some semi-oval protrusions which are designed to control the open and close intervals of the inlet and exhaust poppet valves in the gasoline and diesel engines. Rotation of the cam which takes its movement from the crankshaft via a chain or a trigger belt causes its profile to slide against the smooth flat closed end of a cylindrical member known as a follower. In this study, fracture analysis of a camshaft of an automobile engine is carried out. The analyzed camshaft is fractured after a very short period of usage of the car. For the determination of the failure reason, the microstructure and chemical compositions of the camshaft material are determined. Some fractographic studies are carried out to assess the fracture conditions. A stress analysis is also carried out by the finite element technique for the determination of highly stressed regions on the camshaft.

The automotive sector has reached a very high production capacity in the last decades. Depending on this increasing capacity, its stable growth is anticipated in the world economy. The economic value of the work capacity in the automotive sector is very large and this shows that the automotive sector is the 6th economic sector worldwide. The sector has an interrelationship with more than 300 different fields. So, if there is any malfunction in the main or side industries, the whole functions of the produced cars are influenced. On the other hand, the failure analysis is a special field of study for materials and mechanical engineers. On one side, the materials engineer is intended to develop his/her observational and reasoning skills for the understanding of interrelationship between observable features and properties or performance. On the other side, the mechanical engineer studies on the possible failure locations and types and amount of the existent stress levels. Many studies have been carried out on the automotive failure analysis. Among these, Study has shown that the mostly failed parts are from engine and its components among the automotive failures. This is followed by the drive train failures. Among the studies on the engine component failures in a camshaft using the crack-modeling method. They concluded that the crack-modeling method, which predicts fatigue limits of stress concentrations using a fracture mechanics approach, was able to predict the behavior of an automotive camshaft component in two different design cases under both bending and torsion loading. Moore studied a crankshaft failure and decided that the reason for the failure is fatigue propagation due to combined bending and torsion stresses. The actual level of these stresses as compared to design or expected stress levels in their studied engine was unknown. Cams are designed to control the open and close intervals of the inlet and exhaust poppet valves. The radial cam used for this purpose consists of a circular disc having a semi-oval triangular protrusion. Rotation of the cam causes its profile to slide against the smooth flat closed end of a cylindrical member known as a follower. [1]

The cam profile has a follower lift or valve opening side and a corresponding follower fall or valve closing side. Both the lift and fall sides of the profile can be divided in to three phases which are; the cam ramp, the cam flank and, the cam nose. With the four-stroke cycle engine, the cycle of events of the inlet and exhaust valve opening and closing is performed by the camshaft in one revolution, but the piston strokes (induction, compression, power, and exhaust) are completed in two crankshaft revolutions. Consequently, for the camshaft timing cycle to be in phase with the crankshaft angular movement, the camshaft has to turn at half crankshaft speed, that is, a 2:1 speed ratio. The crankshaft to camshaft drive may be transmitted by three different methods: chain, belt, or gear (Fig.5 a). There are several types of camshaft arrangement including cylinder block mounted camshaft, OHC with injection pump drive for diesel engines, twin OHC drive for gasoline engines etc. [1]

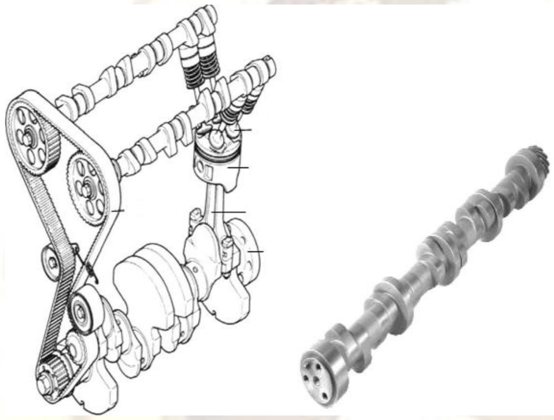


Figure 5 a) Schematic view of camshaft on an engine [2]

The camshafts are generally produced by casting or forging. The cast camshafts are made from modular cast iron. The cam surfaces and journal surfaces are heat treated to obtain hard surfaces. In this study, fracture analysis of a camshaft of an automobile engine is carried out The analyzed camshaft is fractured after a very short period of usage of the car. For the determination of the failure reason, several experimental studies are carried out as well as a finite element stress analysis. The failure is occurred as a sudden fracture at very close to bearing location where there is a stress concentration. The experimental studies include the determination of the microstructure and chemical compositions of the camshaft material. Some fractographic studies are also carried out to assess the fracture conditions.

5.2 Techniques of Experiment:

5.2.1 SEM analysis of fractured surfaces:

Scanning electron microscopy studies are carried out to assess the reason of the fracture. Some casting defects are observed in the fractured surface. There is some gas cavities resulted from the improper casting conditions and these cavities are accumulated at a certain location (Fig. 5.1.1). These cavities cause stress concentration and behave as a crack in the cross-section. With cycling and variable load conditions the whole cross-section is fractured. As the fractured region is itself has a stress concentration due to the overall design and construction of the camshaft (Fig. 5.1.1), these cavities accelerated the fracture. [1]

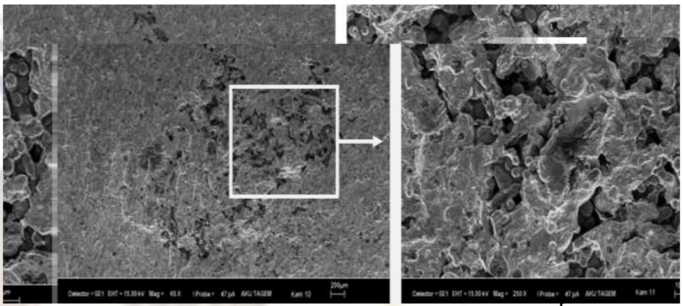


Figure.5.1.1 SEM views of the fractured surface [2]

5.2.2 Finite element analysis:

The stress analysis of the camshaft is carried out for the determination of the stress concentration level at the fracture region by the finite element method. The commercial finite element code, ANSYS 7.0, is used for the analyses. As the camshaft is symmetric at the middle section, only half of the shaft is modeled in the study. The finite element model, loading and boundary conditions are given. The model consists of 22385 SOLID92 elements which is a 10 nodes tetrahedral feature. As the camshaft has a evolutional movement, the angular velocity is also considered in the stress analysis.

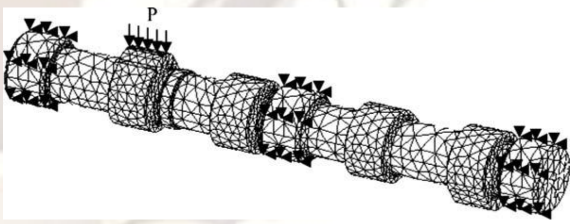


Figure 5.1.2. The finite element model, loading and boundary conditions [2]

During the revolution of the camshaft, each cam is affected by different forces. For the analysis of this different loading condition and for the determination of most dangerous position, 12 stress analyses are carried out by turning the camshaft with 30^0. The most dangerous position of the camshaft is given. As can be seen, the highest stresses occur at the fractured section and at the beginning location of the fracture as shown with an arrow in the fractured section. The stress concentration factor at the cracked section is approximately 4. [1]

In the next chapter dynamic modeling of camshaft is discussed, which is required in design of camshaft, in this SDOF & MDOF is also discussed.

6. DYNAMIC MODELING

The design engineer is able to design appropriate design of products by using mathematical tool which is known as dynamic modeling, it is used to describe the behavior of physical system. In this study dynamic model of camshaft is represented. Every mechanical system has infinite degree of freedom, if degree of freedom is more then more accurate simulation obtained.

6.1 Dynamic Modeling:

Dynamic modeling is a mathematical tool that is used to describe the behavior of physical systems. These systems may be represented by single or multiple differential equations and may be a mechanical, electrical, thermal, or any other time-varying system. In this particular case, only dynamic models for mechanical systems are considered. Every real mechanical system has infinite degrees of freedom. The higher the degree of freedom in the model, the more accurate the simulation will be, at the price of model complexity and computation time.

In order to have a reasonable computation time and acceptable results, the model needs to be simplified. The simplification of model may be done by reducing the degrees of freedom by combining masses, stiffness constants, and damping coefficients. The simplest dynamic model is a single degree of freedom model with one mass, one spring, and one damper. More complex models have multiple degrees of freedom with multiple masses, springs, and dampers. The application of dynamic modeling to cam-follower systems was first seen in the automotive industry in 1953 when a single-degree-of-freedom dynamic model was created with good correlation between experimental and simulated data. Superior correlation was obtained when a twenty-one degree-of-freedom dynamic model was created for the valve-train system. The disadvantage of the latter model was a longer modeling and computational time. Other applications included modeling of a robotic arm with impact and modeling of industrial cam-follower systems.

By creating a dynamic model, the designer is able to determine the behavior of a system prior to expensive manufacture, assembly, and testing. If the requirements are not met, appropriate fundamental changes may be made early on in the product cycle to obtain acceptable behavior. [2]

6.2 Single degree-of-freedom model (SDOF):

A single degree of freedom SDOF model is the simplest dynamic model. An SDOF model can have one or two lumped masses and is typically used as a quick approximation of the dynamic behavior of a system prior to increasing the complexity of the model for a more accurate analysis. [2]

6.2.1 One-mass dynamic models:

One-mass SDOF model is a simplified model used to predict the dynamic behavior of the motion of a system. A dynamic model was developed for the high-speed motion of a cam-actuated engine valve and overhead valve linkage shown in Figure 6.1.1.

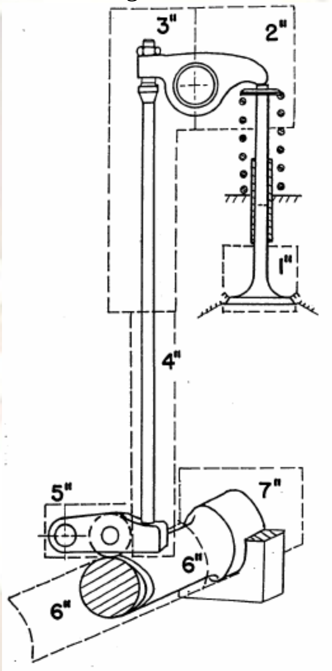


Figure6.1.1 Overhead valve linkage [3]

To simplify the system shown in Figure 6.1.1, divided the valve-train into several concentrated masses, and then relocated the masses to the valve head's axis of translation using the appropriate lever ratios to create one lumped mass. Once the lumped parameters were obtained, equations of motion were developed. To create the equations of motion, the forces acting on the system were identified. These comprised the spring force, inertia force, linkage compression force, friction force, and gas force. The spring force into valve spring compression force, valve spring preload force, and the force produced due to the vibration of the springs. Three types of friction were taken into account for the damping, namely coulomb friction, viscous friction proportional to relative velocity, and viscous friction proportional to absolute velocity. The most complex portion of the equation was determined to be the gas force, which occurred when there was a difference in pressures. The gas force was very complex to model and would have required experimental data which was not readily available, therefore it was neglected. The equations of motion were created for the simplified one mass model shown in Figure 6.1.2. [2]

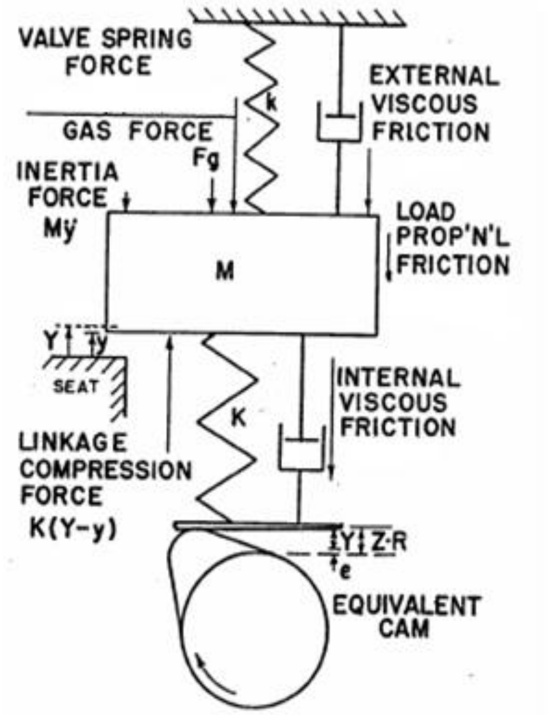


Figure6.1.2 Simplified Valve Train One-Mass Model [2]

$$\ddot{x} + 2\zeta_1\omega_{n\_1}\dot{x} + \omega_{n\_1}{}^2 x = \frac{1}{M}F(t)$$

$$\ddot{x} + 2\zeta_3\omega_{n\_2}\dot{x} + \omega_{n\_2}{}^2 x = \frac{1}{M}F(t)$$

$$\ddot{x} + 2\zeta_2\omega_{n\_2}\dot{x} + \omega_{n\_2}{}^2 x = \frac{1}{M}F(t)$$

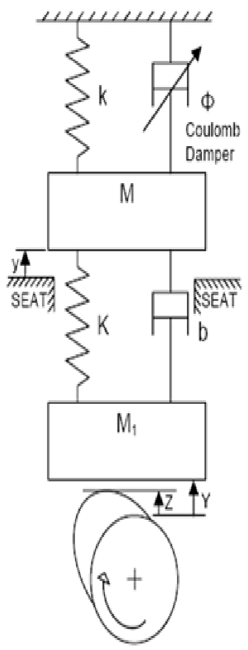
Depending on the cam and follower contact condition. Where $\dot{y} > 0$ (valve opening), $\dot{y} < 0$ (valve closing) and $x < 0$ (valve jumps), respectively. The variable x represents the displacement of mass M with respect to equivalent cam. The validity of a mathematical model when the compared the simulated results with the experimental result. Other works that followed tried to improve upon different aspects of the modeling in attempt to increase accuracy or obtain a better understanding of the problems. Most of the work tried to increase accuracy by increasing the degree of freedom of the spring mode. Determined that the single degree of freedom model is satisfactory as long as it meets two conditions: [2]

1. The excitation amplitudes near the first mode frequency are significantly greater than those at the second mode frequency.
2. The higher mode vibrations are not able to build up over time to high magnitudes.

While condition 2 is true for most cam follower systems where the follower rests on the cam through a large portion of the cycle or the excitations were low and internal damping was enough to damp the excitations. While many researchers have utilized the one-mass SDOF model to perform their analysis, others venture into the two-mass SDOF model and multiple degrees of freedom (MDOF) models.
The advantage of using a one-mass SDOF model is simplicity & disadvantage is a one mass model does not predict the valve jump accurately. Therefore, a multi-mass model was created to eliminate this possibility. [2]

6.2.2 Two-mass dynamic models:

The addition of the second mass in the SDOF model allowed one to determine the contact force between the cam and follower and obtain a more accurate result, and also predict jump more accurately than the one-mass models. The masses in the two-mass model were divided and located at the valve head and the follower. The linkages' flexibilities were modeled and included between the two masses, while the valve head spring connected the mass at the valve head to the ground. With the addition of the above parameters, a two-mass SDOF model was developed and is shown in Figure 6.1.2



$$M\ddot{x} + b\dot{x} + \left[1 + \frac{k}{K} - \frac{\dot{y}}{|\dot{y}|}\varphi\right]Kx = M\ddot{Y} + k(Y+h)$$

$$F_c = b\dot{x} + Kx + \ddot{Y}M_1$$

Figure 6.1.2 Simplified Valve Train 2-Mass 1-DOF Model [2]

Where x, $\dot{x}, \ddot{x}$ are displacement, velocity and acceleration of M relative to equivalent cam follower. The coulomb and viscous dampers were utilized because they improve the accuracy of the dynamic model significantly.

The benefits of two-mass model over one mass model are:

1. Allows calculation of contact force.
2. Predicts jump more accurately.
3. Gives a more accurate comparison to the experimental data.

The disadvantages of the two-mass model were the division of the masses and more complex equations of motion, but the two-mass SDOF model was considered to be the best compromise between accuracy and complexity. When the contact force in the two-mass SDOF model reached zero, separation occurred and the system became a two degree of freedom model or MDOF model. [2]

6.3 Multiple degree-of-freedom model (MDOF):

A multiple degree of freedom model is a dynamic model having two or more degrees of freedom. The higher the degree of freedom, more accurate the simulation will be, at the price of a longer computation time. In order to have a realistic computation time as well as acceptable results, simplifications must be made by reducing the complexity of the model. Most of the complexities of the MDOF models of valve trains involve valve spring modeling. The creation of the MDOF model is similar to that of the SDOF model. Instead of combining masses, spring constants, and dampers into one lumped values, these parameters are divided and lumped into multiple values depending on the level of complexity desired. If the first mode of vibration is the dominant mode, SDOF should be used; otherwise, MDOF may be utilized. A two mass MDOF model, shown in Figure 6.2[2]

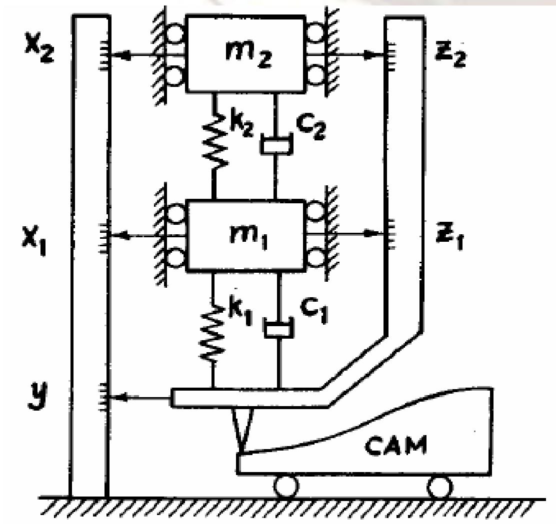


Figure 6.2 Simplified 2-Mass 2-DOF Model[2]

Figure 6.2 has the following equations of motion

$$m_1\ddot{x}_1 + (c_1 + c_2)\dot{x}_1 - c_2\dot{x}_2 + (k_1 + k_2)x_1 - k_2 x_2 = c_1\dot{y} + k_1 y$$

$$m_2\ddot{x}_2 - c_2\dot{x}_1 + c_2\dot{x}_2 - k_2 x_1 + k_2 x_2 = 0$$

Figure 6.2 shows a two-mass two-DOF model of a form-closed system with no return spring. This model did not include a mass where the cam and follower were in contact.

7. CONCLUSIONS

- It is seen that the two-mass SDOF model for a cam follower system determined that the dynamic model for the cam-follower must consist of at least two masses. One of the masses allowed an approximation of the contact force between cam and follower while the other mass was used to predict dynamic behavior. By including an impact and over-travel event.
- It is also seen that third mass was added that represented a striking mass that was used to determine the impact force. Use of this impact model for an industrial cam-follower system can guide mechanical engineers through the designing stage of assembly machines with impact and over-travel more efficiently. This model will allow the elimination time-consuming methods, which will reduce machine development costs and development time.
- It is seen that, The analyzed camshaft is fractured after a very short period of usage of the car. The failure is occurred as a sudden fracture at very close to journal location, where there is a stress concentration.
- The main reason of the fracture is determined as a casting defect. As the failure was related to a material production problem it is likely to affect more than one vehicle. So, the camshaft of vehicles manufactured from that particular series of camshaft should be replaced. Also, the non destructive testing procedures of the component supplier should also be improved as the defect can easily be detectable by standard non destructive techniques.

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