ISSN 2394-739X

International Journal for Research in Science Engineering and Technology

ANALYTICAL DEVELOPMENT & MODAL ANALYSIS OF CRANKSHAFT

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ABSTRACT- Crankshaft is most complicated and highly strained internal combustion engine part, which is subjected to cyclic bending and torsional loads due to gas pressure and inertia forces. These forces induce high bending and torsional stress mainly concentrating at crankpin and journal bearing fillet. In this project, stresses and torsional frequencies are calculated analytically and verified using Finite Element Analysis. Stresses are calculated analytically using the theory of constant energy of distortion at critical location of crankshaft i.e. crankpin and journal bearing fillet and 3-D finite element analysis is carried out using commercial software for single crank throw to study the correlation between analytical and Finite Element Analysis results. Analytical calculations and Finite Element Analysis is done for Top Dead Centre position at rated power operating condition. The calculated force considering the gas and inertia forces is applied at top surface of crankpin to find out the stresses. Torsional frequency has been calculated analytically using Holzer method for free free condition considering torsional stiffness and polar moment of inertia of crank throw. Torsional stiffness is derived analytically and is correlated with finite element results for single crank web Polar moment of inertia is calculated using CAD software. Further finite element model analysis is carried out at component level to study the torsional frequency correlation between analytical and Finite Element results. The stresses, torsional frequencies and torsional stiffness observed from FE analysis are well correlated with analytically calculated results.

Keywords- [Crankshaft, finite element analysis, modal analysis]

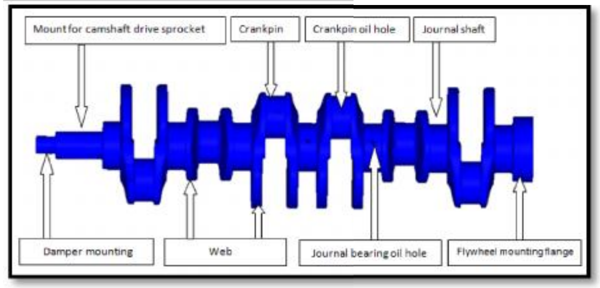
1. INTRODUCTION

The main aim is to study the crankshaft for static strength by considering constant energy of distortion theory in analytical method and in Finite Element method to find out the high stress concentration locations. Also, study the torsional frequency and mode shape by considering Holzer method in analytically and by using commercial software in FE method for dynamic analysis. The stresses and torsional frequencies observed from FE analysis are well correlated with analytically calculated stresses and torsional frequency.

Crankshaft is the main part of the engine which undergoes cyclic bending and torsional load due to forces acting on it. These forces induce high bending and torsional stress mainly concentrating at crankpin fillet and journal bearing fillet. So fillet location treated as the critical location on crankshaft and fatigue failure start at this location. So it is necessary to study the crankshaft statically and dynamically to find out the critical locations and it torsional frequency to avoid the failure and to improve the service life of crankshaft at operating condition.

For an internal combustion engine main important components are Crankcase, Crankshaft, Connecting rod, Cylinder head, Camshaft and these components are typically referred as 5 'C' of engine. Of this crankshaft is largest component with complex geometry and high weight, which converts reciprocating motion of piston to rotary motion with four link mechanism and it is considered as backbone of engine. Converting reciprocating motion into rotary motion is essential because it is easy to handle rotary motion and can be used drive transmission, pumps, compressors, etc. As the power generating from the engine (power stroke) is pulsating in nature there will be speed variations in the rotary motion of crankshaft, therefore to swipe out these variations in rotary motion of crankshaft, due to gas forces it needs flywheel. To the other end crankshaft a pulley is mounted which drives the alternator pulley and fan pulley, which is necessary for vehicle to be self-contained of electric power and cooling of engine respectively. Thus, in an engine crankshaft works in conjunction with flywheel and pulley.

Crankshaft mainly consists of crankpin, journal shaft, small and big web, oil hole at crankpin and journal, fillet between web and crankpin or journal as shown in figure



2. LITRATURE SURVEY

1) SAE 2007-01-0258 Dynamic Load Stress Analysis of a Crankshaft

The paper describes the dynamic simulation of single cylinder crankshaft. Stress variations with engine speeds are calculated. From this paper it is clear that dynamic loading analysis of crankshaft results in more realistic stresses than static analysis and these accurate stress results is critical input for fatigue analysis and optimization.

2) SAE 2009-01-0261 A Study on Diesel Engine Crankshaft Fatigue Performance Optimization

This paper says that crankshaft durability is directly related to its fatigue strength since it works under cyclic loading conditions during its service life. The author mentions the critical areas of crankshaft geometry and avoiding failure of crankshaft there should not be stress concentration in these critical areas. It is also mentioned that processes like fillet rolling helps to improve the fatigue strength of crankshaft.

3) SAE 1999-01-1748 Experiment and Computation Analyses for Torsional Vibration of Crankshaft System with Viscous Torsional Damper on Diesel Engine

In this paper experiment results were compared with computation analysis results for torsional vibration on a crankshaft for diesel engine. The estimated stiffness was used to calculate the natural frequencies of the torsional vibration without the damper by dynamic stiffness matrix method. As a result, the calculated natural frequencies approximately agreed with the measured ones.

4) SAE 2005-01-2273 Measurement of Torsional Natural Frequencies, Moments of Inertia and Torsional Stiffness of Shafts

This paper presents a method to measure torsional natural frequencies and to calculate moment of inertia and torsional stiffness of a shaft. The concepts of equivalent mass moment of inertia and equivalent torsional stiffness are used to model the shaft.

5) A Handbook on torsional vibration Author-E .J. Nestorides

The book gives an idea about the torsional vibration of crankshaft and guidelines to find out analytically the polar mass moment of inertia, torsional stiffness, natural frequency of crankshaft. The book also focuses on evaluation and prediction of torsional vibration stress, vibration amplitude etc.

6) Rules and guideline for design of crankshaft Published By – Germanischer Lloyd SE, Hamburg

This note gives the basic idea about the design of crankshaft for diesel engine. Also describes the methodology to design the in-line and v- type engine by calculating the stress concentration factor , bending stress, torsional stress and equivalent stress at critical areas like crankpin fillet, journal fillet and crankpin oil hole.

***7)* Crankshaft without torsional vibration resonance Patent No.: 5,007,306. Date: 16 April 1991-**The patent states that main reason for torsional vibrations of engine is the torsional vibration resonance due to identical geometries of crank of prior art crankshaft. Natural frequency of torsional vibration of crank is proportional to the square root of rigidity of crank and the rigidity of crank is proportional to fourth power of outside diameter of main journal. Therefore identical outside diameters of main journal causes the torsional resonance of crankshaft.

3. DEGREE OF FREEDOM

To study the modelling of the rigid bodies and its constrains it is required to describe the determination of degree of freedom in a mechanical system. We have to consider that for any body which is in a three dimensional space will have six degrees of freedom. It is very important in a system model that for an analysis we can determine and understand the total degree of freedom. This can be achieved by using the Gruebler equation:

Total DOF= 6*(Number of parts-1)-(Number of constraints)

Let us consider a four bar mechanism. The mechanism forms a single loop comprising threemoving parts and the fixed ground part.Revolute joints are used to constrain two of the parts to the ground and a motion is applied at one of theseto impart movement to the system.An initial modelling attempt might consider all four joints as revolute joints as the likelihood is that in the realmechanism they would all appear similar. Let us apply the Greubler equation and get the degree of freedom

Parts	6*(4-1) = 18
Revolutes	-5*4= -20
Motion	-1*1= -1
Total DOF	= -3

The total sum of the degrees of freedom for this system is negative, whichis physically impossible but has resulted through the selection of the jointsand the introduction of redundant constraints.

4. FORCE ELEMENTS

There are two types of force systems in a force system. The first of these are force elements that can beconsidered internal to the system model and involve the effects of compliance between bodies. These forces have a connection between two bodies and therefore they are called the action reaction forces based on the Newton's third law of motion.

The second type of the force is the external force and is the force which is applied to the system like the gravitational force, the aerodynamic force etc. So as compared to the above forces it can be referred as the action forces only since the reaction on the other bodies is not required.

By considering the definition of the above force elements with respect to the model that we can conclude by taking into account by the formulation of equations for the force and moments which are acting on the body. To specify the magnitude the applied force or movement can be defined using an equation.

5. SOLING THE EQUATIONS

Once the model has been made ready the main code can be used to carry out the dynamic analysis. Dynamic analysis is carried out on the system with one or mode degree of freedom. The different equations representation the system are automatically formulated and then numerically integrated to provide the results at later times.

The multi-body system programme solves both the linear and non-linear equations during analysis. Linear equations can be assembled in the matrix form as shown below.

[A] [x] = [b]

Where

[A] is a square matrix of constants

[x] is a column matrix of unknowns

[b] is a column matrix of constants

The formulations in a multibodysystems program generally lead to amatrix [A] where most of the elements are zero. Such a matrix is called as a sparse and the ratio of the non-zero terms to the total matrix elements is called as sparsity of the matrix.The computer solvers that are developed inmultibody systems to solve linear equations can be designed to exploit thesparsity of the [A] matrix leading to relatively fast solution. This is one of the reasons why programs solve complex engineering problems in a very less time with no improvement in hardware. The further approach of the solution is to decompose the matrix in the upper and lower triangular matrix.

[A]= [L][U]

Where

[L] is a lower triangular matrix

[U] is a upper triangular matrix

In the case of non-linear equations iteration method has to be approached to get a solution. Non-linear equation can be given as follows,

[G][x]=0

Where

[x] Is a set of unknowns?

[G] is a set of functions dependent on [x]

We can get the solution by the use of Newton- Raphson method. This is a iteration based method which is based on assumptions that at very near to the solution the curve can be taken as a straight line when it cuts the axis. This method can be intensified to get fast solutions.

For a dynamic system that is having more than one degree of freedom the solution for its non-linear equation is the essence of analysis the of engineering problems. A number of processes have been developed like the Backward Differentiation Formula, which is having two phases. The first phase is to make the use of the polynomial fit through pass of a specific equation to estimate a value at the next step. The next step is to use Newton-Raphson Method as described earlier to clear the estimation and and to get convergence. Thus we can see to this integration process a as a combination of two distinct phases in which we predict in the first phase and then we correct it in the second phase. By using this type of approach we can say that at the start of the solution we may step forward or backward but as we go further with a suitable scheme there will be a progress in solution.

CONCLUSION

1. The analytical method is developed using the synthesis of the crankshaft.
2. This method deals with the crank systematically.
3. The calculations by the given method perfectly match with the results of ANSYS.
4. As a result the computational cost will be greatly reduced.
5. This method is being used with optimization software to get quick results.
6. This method insights the problem properly.

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