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Dynamic Analysis of Four Cylinder Diesel Engine Crankshaft by Using Holzer Method and Finite Element Method

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Abstract*: In this paper, by using the Holzer method and the finite element method the natural frequencies of torsional vibration of a multi cylinder, four –stroke diesel engine are determined. The natural frequency of a system is important as it is main cause of various types of failures. Also legislative and market pressures on internal combustion engine design call for increased engine power, reduced engine size and improved fuel economy, simultaneously. Also, efforts to reduce engine vibration and radiated noise while improving durability and reliability have become increasingly important to the automotive industry due to more stringent requirements for higher performance, lighter weight, low cost, and fast to market engine designs. Optimized engine components are therefore required if competitive designs must be realized. Sophisticated analytical tools can greatly enhance the understanding of the operation of vital engine components. This is particularly true for crankshafts, one of the most analyzed engine components. Many sophisticated analysis methods have been reported in the past. This has been mostly facilitated by the use of the finite element method on high speed computers and the availability of elaborate finite element preprocessors which can construct complex finite element mesh models.
Keywords: Crankshaft, Holzer Method, Diesel Engine, Natural Frequency,

I. INTRODUCTION

In recent years, noise, vibration and harshness (NVH) of automotive engines is becoming an integral part of the design process along with the traditional issues of durability and performance. NVH is strongly related to how customers perceive the quality of the engine, affecting, therefore its competitiveness in the market place. Extensive static and dynamic analysis has been performed on vital engine components as crankshafts and engine blocks in order to improve their durability and NVH performance. The engine is a fine tuned system of individual components. An optimum engine design requires a system approach since the performance of each component can be strongly dependant on the performance of the other components. This is particularly true for the crankshaft assembly.

A crankshaft is subjected to many periodical dynamic loads, generating vibrations and consequently stresses that shall be quantified to ensure the structural integrity of the component.

A crankshaft assembly consists of the crankshaft, main bearings, flywheel and pulley.

II. LITERATURE REVIEW

Dr ChRatnam, K N S PrakasaRao[1] determined the natural frequencies of torsional vibration of a multi-cylinder, four 4-stroke diesel engine crankshaft by the transfer matrix method (TMM). The natural frequency of a system is important as it is the main cause of various types of failures. Therefore by knowing the natural frequencies and frequency modes of the engine the limitations in use of the engine working speed can be fixed. The natural frequencies and mode shapes of multicylinder, four stroke diesel engine crankshaft obtained through FEM also.

Dubensky R.G. [2] presented Crankshaft concept design flowchart for product optimization in which one of the aspect is viewed for torsional vibration. According to this flowchart, preliminary dimensions are specified based on engine design data and previously designed comparable components. This preliminary design should verify for rigidity, deformations, static strength, and fatigue strength under different load-case scenarios (i.e. bending, torsion, and combined bending and torsion loading conditions) considering appropriate factor of safety.

IlyaPiraner, Christine Pflieger, [3] described a two-stage process adopted by Cummins for crankshaft analysis. The first stage is a simplified analysis, which combines a “quasi-static” crankshaft model and a rigid hydrodynamic bearing model to address crankshaft fillet bending stress. Stresses at various locations in the crank are calculated by using sets of unit load cases applied to a FE model. The appropriate unit load cases are scaled to the load, and combined to calculate the stresses in the crank. The process is repeated in an efficient manner to simulate multiple engine conditions for rapid crankshaft and bearing preliminary design.

Meirelles P. S., Zampieri D.E. [4] studied the crankshaft torsional vibration phenomenon in internal combustion engines. The formulation, based on state of equation solution with system steady state response calculation performed by transition state matrix and the convolution integral. From the torsional vibration analysis, it is possible to obtain the dynamic loading on each crankshaft section and these loads can be applied as boundary conditions in a finite element model to predict the safety factor of the component and compare the system behavior.

Jonathan C. Reynolds [5] presented the highlights and requirements that were undertaken to create a design package or tool that will reduce the initial design time to produce a preliminary CAD model of a specific crankshaft. The user can input and select key information pertaining to the specification of a crankshaft and the preliminary process of calculating various influential factors on geometry and dimensions of the crankshaft are automated with the end output result being a 3D CAD model for any crankshaft. Here the Natural Frequency of the crankshaft determined by using Model FE analysis and Holzer Method.

III. THEORETICAL MODELING

The crankshafts are subjected to torsional, axial and flexural vibrations, due to the periodic nature of the excitation loading. The crankshaft is mainly loaded by the engine operating load which comes from the cylinder combustion. The load is transmitted through the piston and connecting rod to the crankpin of the crankshaft. The piston and the connecting rod are treated as rigid bodies and their inertia loads are calculated and combined with the combustion load. Optimization of the crankshaft requires a determination of an accurate assessment of the loading which consists of bending and torsion.

A. Influence of crankshaft vibrations:

The crankshaft vibrations badly affect the working of engine. The major areas are as follows.

1) The torsional vibrations cause the angular velocities of all the cranks to vary but not in the same proportions. The crank away from the node has maximum effects compared to crank near the node. This affects the balancing.
2) Due to same reason discussed above, stresses of varying intensity are generated in whole length of the crankshaft. These are also fluctuating in nature and hence cause fatigue of crankshaft, reducing its life. The stresses induced are dangerous at fillet or oil-hole locations.
3) Vibratory energy is transmitted to all parts of the structure where it causes structural damage.
4) It induces noisy operation of engine, which is undesirable in passenger cars. It also causes wear of all running parts.

To avoid some of the above results a good diagnosis of crankshaft vibrations is required. The analysis should be carriedoutto find the various natural frequencies so that the critical speeds can be avoided. The dynamic response and stresses induced at all critical locations should be found out. A stress cycle should be identified so that the fatigue cycle can be estimated and depending upon that the life prediction can be done. Apart from this the need for the torsional vibration damper can be identified so that tuned damper or absorber can be fitted on engine.

B. Torsional Natural Frequency

The determination of torsional natural frequency is can be performed in two ways like Holzer calculation and model finite element analysis

1) Holzer Method: It is essentially a trial and error scheme to find the natural frequencies of undamped, damped, semidefinite, fixed vibrating systems involving linear and angular displacement. A trial frequency of the system is first assumed, and a solution is found when the assumed frequency satisfies the constraints of the system. Also it involves the crankshaft system as a series of inertia discs joined with massless springs with torsional stiffness value. The individual inertia discs represent portions of the crankshaft that would be considered to be able to twist in relation to a portion next to it. The spring joining the two representing a portion of material between the two portions of crankshaft that would resist the twisting motion. How the crankshaft is split up will have an effect on the accuracy of the results. Figure 1 shows an example of an inline 4-cylinder crankshaft with flywheel and pulley either ends split upto chosen inertia discs to be evaluated. Figure 2 shows the representation of split crankshaft as simple discs ‘In’ and the spring stiffness value that join them together, ‘kn’.

The general representation of a shaft having many rotors is as shown in Figure 3.The rotating shafts can be modeled as a lumped parameters having discs of inertia J and shafts, which are inertia less, and having stiffness K.

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The equations of motion can be written as,
For each rotor;

$$(K_1 - J_1\omega^2)\phi_1 - K_1\phi_2 = 0\ldots\ldots(1)$$
$$-K_1\phi_1 + (K_1 + K_2 - J_2\omega^2)\phi_2 - K_2\phi_3 = 0..(2)$$
$$-K_2\phi_2 + (K_1 + K_3 - J_3\omega^2)\phi_3 - K_3\phi_4 = 0\ldots.(3)$$
$$-K_{n-1}\phi_{n-1} + (K_{n-1} + K_n - J_n\omega^2)\phi_n = 0\ldots.(4)$$

fig 1 Inline 4- cylinder crankshaft

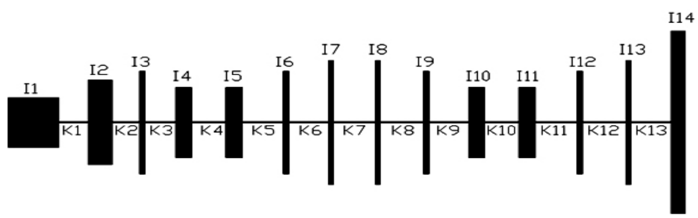

Fig 2 Representation of split crankshaft

C. Mathematical Deriation

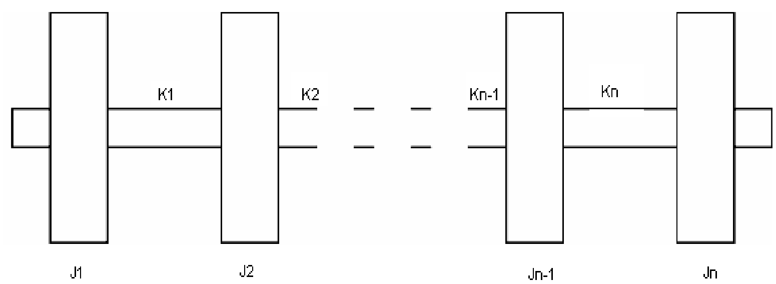

Fig 3 A general shaft rotor systems

This can be written in matrix form as

$$\{ [K] - \omega_i^2 [J] \} \{\phi\} = 0\ldots..(5)$$

Where [K]is the stiffness matrix, [J]will be inertia matrix. The equations can be well arranged so as to get branded matrices which can be solved for ω_i' using iterative techniques, transfer matrix methods, finite element methods, etc.

If discs are arranged as shown in Fig.3, the inertia torques can be written as

$$T_1 = J_1\omega^2\phi_1\ldots\ldots\ldots.(6)$$
$$T_2 = J_1\omega^2\phi_1 + J_2\omega^2\phi_2\ldots\ldots.(7)$$
$$\vdots$$
$$T_n = {}_{i=1}\sum^n J_i\omega^2\phi_i\ldots\ldots\ldots..(8)$$

Substituting eq^n. 6 to 8 into eq^n. 1 to 4 it can be written as,

$$\phi_2 = \phi_1 - T_1 / K_1\ldots\ldots.(9)$$
$$\phi_3 = \phi_2 - T_2 / K_2\ldots\ldots..(10)$$
$$\phi_n = \phi_{n-1} - T_{n-1} / K_{n-1}\ldots\ldots...(11)$$

Eq^n,8 is first solved by trial and error, with $\phi_1 = 1$ for ωsuch that $T_n = 0$; this will be natural frequency. Then using eqn. 9 to 11, the deflections at various rotors can be obtained to plot the mode shapes.

Fig. 4 shows a general variation of residual torque T_n versus trial frequency ω. The plot cuts frequency axis at natural frequencies.

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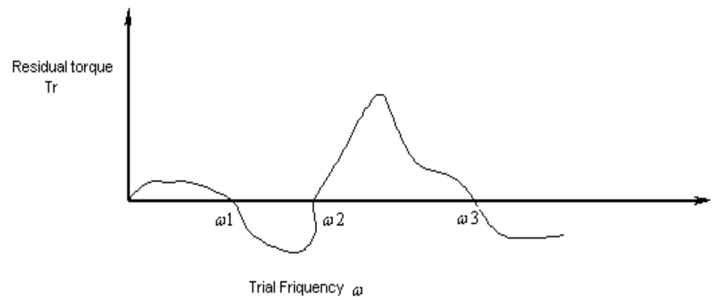

Fig 4 General Variation of Residual Torque Vs Trial Frequency

D. Finite Element Analysis

It is not always possible to obtain the exact analytical solution at any location in the body, especially for those elementshaving complex shapes or geometries. Always what matters are the boundary conditions and material properties. In such cases, the analytical solution that satisfies the governing equation or gives extreme values for the governing functional is difficult to obtain. Hence for most of the practical problems, the engineers resort to numerical methods like the finite element method to obtain approximate but most probable solutions.

Finite element procedures are at present very widely used in engineering analysis. The procedures are employed extensively in the analysis of solids and structures and of heat transfer and fluids, and indeed, finite element methods are useful in virtually every field of engineering analysis.

The Finite model analysis simply searches for all modes of vibration. The mode of torsional vibration of whole crankshaft about the centerline is required. Once found, the software provides the frequency at which this mode vibrates naturally, i.e. the natural frequency.

E. Results for Crankshaft of one of the specific Automobile Company

The analysis is done using the program and following data,

TABLE I

Data for a specific Engine Crankshaft

Sr. no.	Component	Mass (kg)	M.I (kg-m^2)
1.	Piston	0.8	—
2.	Piston rings (all 3)	0.0485	—
3.	Piston pin	0.295	—
4.	Connecting rod	0.6708	—
5.	Crankshaft	12	—
6.	Crankshaft pulley	0.90	0.012
7.	Flywheel	5.50	0.2174

F. Results

The natural frequencies for above system in Hz are,

Mode. No.	7	8	9	10	11
Natural Frequency by Holzer method	433.2	902.42	993.44	1049.34	1132.12
Natural Frequency by ANSYS	408.87	571.47	937.11	1047.43	1054.34

From above table we found the ANSYS results are agree with Holzer method results.

IV. CONCLUSIONS

A formulation to calculate the torsional vibration of internal combustion engine crankshaft was presented. It includes Holzer method, which is essentially a trial and error scheme to find the natural frequencies of vibrating system involving linear and angular displacement. For trail frequency of the system is first assume, and the solution is found when assumed frequency satisfies the constraint of the system. This generally requires several trials. Depending on trial frequency used the fundamental as well as the higher frequencies of the system can be determined. The method also gives the mode shapes. The holzer method can also be applied to a system with fixed ends. The torsional natural frequency of a 4- cylinder 4-stroke diesel engine crankshaft is determined by using Holzer method and Finite element method and they are found in good agreement.

REFERENCES

[1] Dr.ChRatnam., K N S PrakasaRao., "Frequency analysis of a multicylinder Four-stroke Diesel Engine Crankshaft by using the Transfer Matrix and Finite Element Method.", Journal of Institute of Engineers (India),vol.86, 6 Apr 2005.
[2] Dubensky R.G., "Crankshaft Concept Design Flowchart for Product Optimization",SAE Technical Paper No.2002-01-0770, Society of Automotive Engineers, 2002.
[3] IlyaPiraner, Christine Pflieger, Oliver Bouthier, "Cummins Crankshaft and Bearing Analysis Process", Cummins, Inc.2002 North American MDI user conference. Pp1-13
[4] Meirells P.S., Zampieri D.E., "Mathematical Model for Torsional Vibration Analysis in Internal Combustion Engine",World Congress, France, 2007.
[5] Jonathan C. Reynolds., "Crankshaft Design and Analysis package",Swansea Institute of Higher Education, Wales. UK.
[6] Henry J., Topolsky J., "Crankshaft Durability Prediction – A New 3-D Approach", SAE Technical Paper No.920087, Society of Automotive Engineers, 1992.
[7] Zissimos P. Mourelatos.,"A crankshaft system model for structural dynamic analysis of internal combustion engine", General Motors Research and Development and Planning, USA .6th June 2001.
[8] Yu V., Chien W.Y., Choi K.S, "Testing and Modeling of Frequency Drops in Resonant Bending Tests of Notched Crankshaft Sections",SAE Technical Paper No.2004-01-1501, Society of Automotive Engineers, 2004.
[9] Guagliano M. and Terranova A., "Theoretical and Experimental study of the stress Concentration Factor in Diesel Engine Crankshaft", Journal of Mechanical Design, vol.115, pp.47-52.
[10] Prakash V., Aprameyan K., "An FEM Based sapproach to Crankshaft Dynamics and Life Estimation ",. SAE Technical Paper No.980565, Society of Automotive Engineers, 1998.
[11] P.Seshu., "Textbook of Finite Element Analysis", Prentice-Hall of India Pvt. Ltd New Delhi, , 2005,Chapter 7,pp 295-303
[12] Singiresu S Rao, "Mechanical Vibrations", Pearson Education, Delhi. (4th Edition).