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A review on vibration analysis of crankshaft of internal combustion engine

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Abstract - ***Crankshaft is mechanical component with a complex geometry which transforms reciprocating motion into rotational motion. The conversion of reciprocatory motion of the crank to rotational motion in an IC engine is done by the crankshaft. Crankshaft plays a pivotal role in its functioning. The stress and fatigue that the crankshaft can handle decides the satisfactory working period of crankshaft. Any defect in the crankshaft deteriorates the performance of the engine. Faults in crankshafts can result in degradation of the engine and lead to losses in terms of revenue. Hence, it is important to analyze the crankshaft and predict its failures before a severe catastrophe occurs. Vibrations give a good amount of information on the characteristics of the vibrating structures and hence vibration analysis can be used to inspect and evaluate the crankshaft. In this paper, a brief review of analyzing crankshaft by means of vibration analysis which forms an integral part in almost all the fields is done.***

Key Words: *Crankshaft, Vibration analysis, Fast Fourier transform, ANSYS, LabVIEW, MATLAB Software.*

1. INTRODUCTION

The advancement in industry and technology leads to the need of low cost but highly reliable devices. Internal Combustion (I.C.) engine is one of the most important devices of the industry which converts chemical energy to mechanical energy. Therefore, there is a constant need for highly efficient and durable I.C. engines. Crankshaft is the most significant part of the I.C. engine which converts linear motion into rotational motion. Any defect or failure in the crankshaft will lead to the failure of the I.C. engine [1]. The following figure shows the I.C. engine assembly consisting of the crankshaft and the other parts.

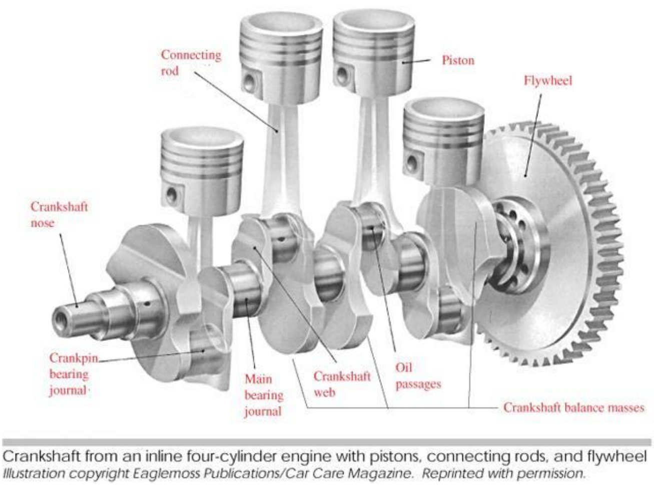

Figure 1. Crankshaft with the entire I.C. engine assembly [2].

Crankshaft mainly consists main bearings, the crankpins, connecting rods, the crank arms [3]. Thus, the crankshaft plays an important role in the functioning of the engine. Due to extreme level of combustion taking place in the engine, large amount of load is transmitted from the connecting rod to the crankpin[1]. The crankshaft has to sustain all the stress and the power strokes due to the gas combustion for unobstructed functioning of the engine [4]. Hence, to avoid any severe catastrophe or failure of the engine, it is significant to analyze the crankshaft by appropriate means.

2. VIBRATION ANALYSIS

Vibrations play a pivotal role in our day-to-day lives like in the human anatomy; for voice to be generated the vocal cords need to vibrate, for legitimate walking the leg muscles must vibrate etc. A periodic oscillation can be termed as vibration [5]. There can be different types of vibrations which can be classified as shown in figure 2.

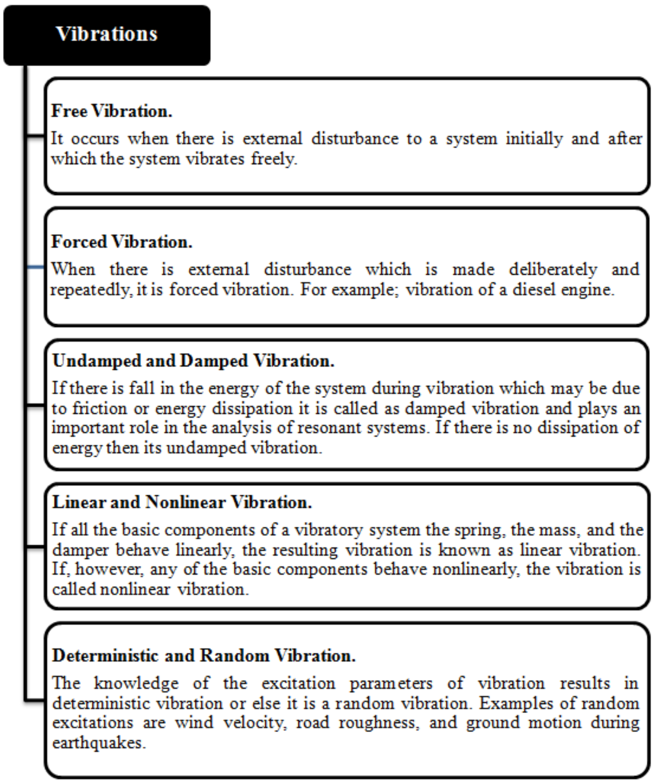

Figure 2. Classification of vibrations [5].

Sometimes vibrations can be a result of faults, like in the case of machines like pumps or generators. Sometimes, vibrations are generated due to external forces; for eg.; powerful winds shaking an improperly built suspension bridge. If the frequency of these external sources of vibration matches with any of the natural frequencies of the system, then the system undergoes dangerously large oscillations. This condition is known as resonance. Breaking of bridges, turbines and wings of airplanes are a few cases of structure failure due to resonance[5].

Figure 3. Tacoma Narrows Bridge an example of structure failure due to vibrations.

Hence, it is important to analyze a given structure for vibration. There are numerous techniques by which vibrations of different structures can be monitored as shown in figure 4.

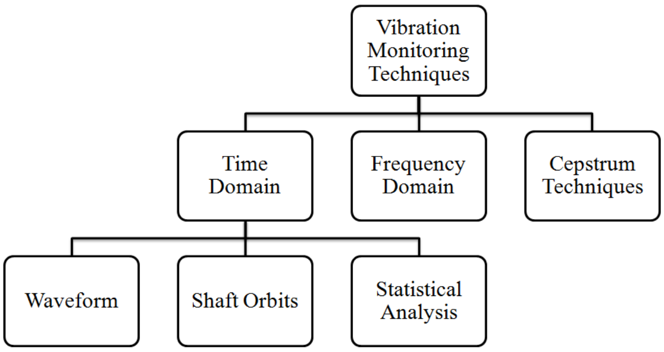

Figure 4. Vibration Monitoring Techniques [5]

Vibration signals can be analyzed in frequency domain and time domain. Now-a-days vibration analysis deals with FFT (Fast Fourier Transform) which is a part of discrete fourier transform or a part of analysis in frequency domain. Analysis in the frequency domain is however, more useful in the machines incorporating rotating elements like that of the bearings [5].

3. CRANKSHAFT VIBRATIONS

The different types of vibrations that a crankshaft can undergo are torsional, flexural, axial, coupled. All the four types of vibrations are compared on the basis of the available literatures as follows:

Table -1: Comparison of crankshaft vibrations [3][6]

Parameters	Torsional	Flexural	Axial	Coupled
Cause	The fluctuating torque at the crankpin causes the periodic twisting or untwisting of the crankshaft leading to torsional vibrations	When the crankshaft is under the influence of some forces which are fluctuating in nature and the crankshaft follows a lateral but periodic motion then the	Torsional vibrations lead to axial vibrations	All the types of vibrations when coupled together lead to coupled vibrations. It occurs mainly so that any one type of vibration cannot occur independently.

		crankshaft is said to undergo flexural vibrations		
Severity	Most dangerous, if not controlled, it can break the crankshaft	Do not affect the crankshaft seriously due to low intensity	Very seldom affect the crankshaft, but can cause failures in marine engines.	Not troublesome because the frequency of these vibrations is far away different than the natural frequency of the crankshaft.
Solutions	Torsional dampers can be attached at the free ends of the crankshaft. Frictional, rubber, viscous, spring dampers can also be used.	--	--	--

It is evident from the above comparison that the torsional vibrations are the most dangerous vibrations that a crankshaft can undergo which can lead to high intensity failures. Vibrations can cause structural damage to the crankshaft. Its fluctuating nature can cause fatigue of crankshaft reducing its life and lead to noisy operation of the engine. Torsional vibrations affect the balancing of the crankshaft [3].

4. CRANKSHAFT VIBRATION ANALYSIS

Now-a-days, Noise, Vibration and Harshness (NVH) are the factors which decide the quality of the internal parts. The NVH criteria is primarily used in the designing process for better products. The crankshaft is analysed by Finite element methods for better construction and also in recent years we have the Finite element pre-processors that help us in the process [1].
The following table shows the softwares used and the results of the vibration analysis carried out by different references:

Table -2: Crankshaft vibration analysis

Sr. No.	Reference	Software		Result
		Modelling	Analysis	
1.	K. Thriveni, Dr. B. Jaya Chandraiah [4]	CATIA-V5	ANSYS	Huge quantity of deformation and stress is seen at the centre and the fillet areas of the crankshaft respectively. An optimum quality of crankshaft is designed as the Von misses stress is less than the yield stress as required [4].
2.	Rinkle Garg, Sunil Baghla [7]	Pro/E	ANSYS	If the strength of the crankshaft is improved by reducing its weight, it will lead to reduction in cost & increase in performance [4][7].
3.	Gu Yingkui, Zhou Zhibo [8]	Pro/E	ANSYS	The knuckles of the crankarm is the main area of stress [4][8].

4.	Abhishek Choubey, Jamin Brahmbhatt [9]	Solid Works 2009	ANSYS	Huge quantity of deformation and stress is seen at the centre of the neck of the crankpin and the fillet of the edge of the main journal of the crankshaft respectively. An optimum quality of crankshaft is designed as the Von misses stress is less than the yield stress as required [9].
5.	R. J. Deshbratar, Y. R. Suple [10]	Pro/E	ANSYS	Huge quantity of deformation and stress is seen at the centre and the fillet areas of the crankshaft respectively [4][10].
6.	Jian Meng, Yongqi Liu, Ruixiang Liu [11]	Pro/E	ANSYS	A considerable amount of of deformation which is bending in nature occurred under the influence of lower frequency and stress is seen at the centre of the main bearing journal and crankpin of the crankshaft [9][11].
7.	Sanjay B. Chikalthankar, V M Nandedkar, Surender Kumar Kaundal [12]	Pro/E	ANSYS	Huge quantity of deformation and stress is seen at the centre and the fillet areas of the crankshaft respectively. Realistic inferences can be obtained by Dynamic loading analysis in comparison with static analysis [12].
8.	K. Thriveni, Dr. B. Jaya Chandraiah [13]	CATIA-V5	CATIA-V5	Modal analysis has been performed for : Free frequency, where vibrations take place in crankshaft due to its self weight; the resonance frequency appeared in the 7th mode of vibration. Frequency case in which the vibrations are forced (boundary conditions are applied) with the minimum frequency at 1st mode and the maximum frequency at 10th mode [13].

Many of the references have used the concept of Von Misses Stress for analyzing the crankshaft.

Von Misses Stress is basically a criterion which decides whether there will be a failure in the material or not, due to stress. If there are stresses on a material from different directions i.e.; x, y and z directions, then Von Misses Stress gives a formula by which, the stresses in different directions can be combined as a single von misses stress. This Von Misses Stress is an index which when compared with the yield stress of the material if comes out to be more, then the material is said to be in a state of failure. [12].

In [14], a test rig for vibration analysis is setup, the vibration signals are obtained through accelerometers, dynamometers, torque sensors etc; these signals are then amplified and acquired through the DAQ card (Data Acquisition Card) and sent to LabVIEW, where they are analyzed and faults are found out.

Thus, taking into account the analysis carried out in the literatures till date, the flow chart shown in figure 5, can be followed if one wishes to perform vibration analysis on crankshaft. According to the flowchart, the first step will be the literature survey of the crankshaft you wish to analyze. After obtaining an adequate amount of knowledge about the crankshaft, it can be modelled in softwares and the model can be simulated and analyzed. The simulation results can be validated in hardware, for which we require a crankshaft. The crankshaft needs to be tested for balancing before analyzing it for vibrations. The reason for testing it for balancing is that; since the crankshaft is rotating with the stress and load from the piston, connecting rod etc. it sometimes loses its balance and causes vibrations. Disproportionate diversification of the angular velocities of the crankshaft is produced due to torsional vibration which affects the balancing; hence it is important to test the crankshaft for balancing [15]. A test rig should be set up, wherein the crankshaft will be rotated at different rpms and using the sensors like accelerometers, dynamometers, torque sensors, proximity sensors etc,; the vibrations can be checked. This data can be acquired by using the NI DAQ and the sensed signals can be analyzed in LabVIEW. In this way, the crankshaft can be analyzed for vibrations and an optimal design of the crankshaft can be obtained.

Different vibrations together lead to formation of stresses in the entire length of the crankshaft which causes fatigue in it, curtailing its life. The stresses which appear mainly in the fillet or oil-hole locations prove disastrous for the working of the crankshaft. This vibratory power causes wearing of the parts and causes disturbance such as noise. These vibrations abominably disturb the functioning of the IC engine in numerous ways. This makes the analysis of crankshaft for vibrations and hence noise as important as testing the IC engine for efficient working and maintenance.

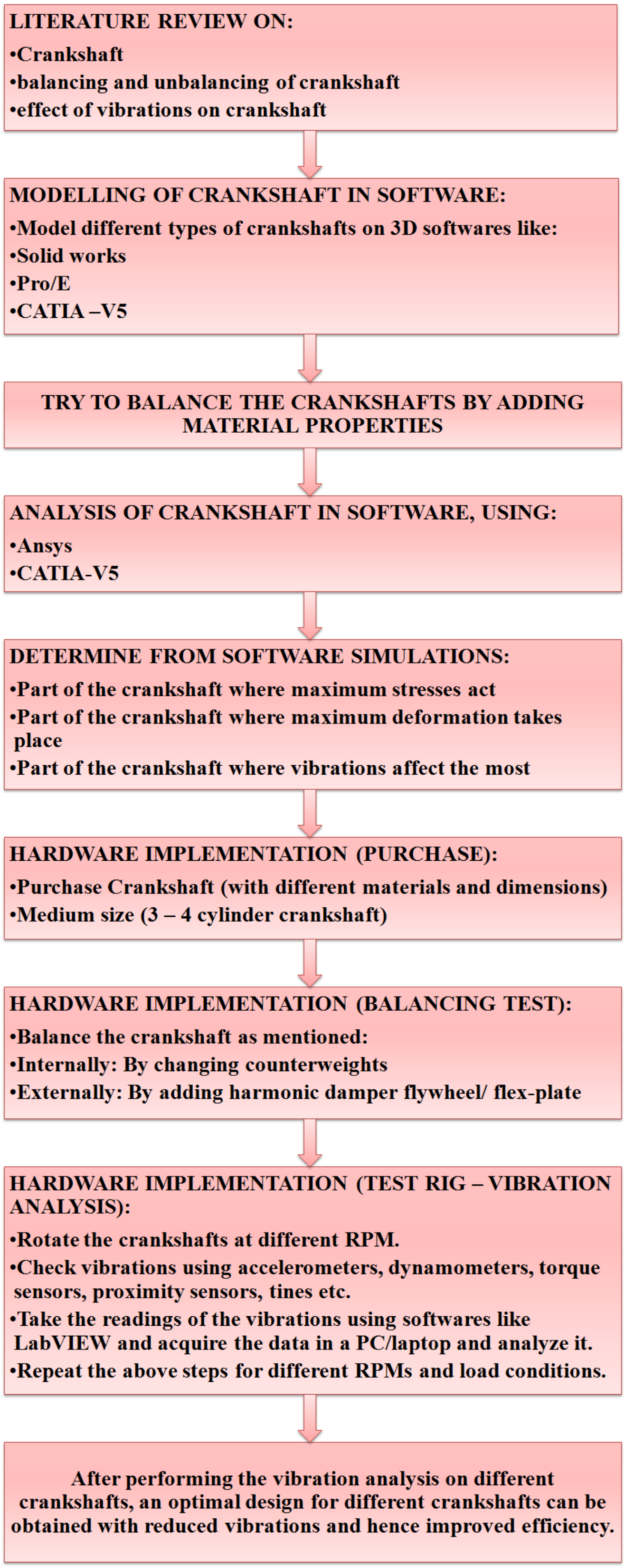

Figure 5. Flowchart for vibration analysis of crankshaft

5. CONCLUSIONS

It can be concluded that out of the four types of vibrations (torsional, flexural, axial, coupled) which affect the crankshaft, torsional vibrations are the most dangerous which can break the crankshaft.

The crankshaft vibration analysis process can be summarized in two steps. First step consisting of modeling of the crankshaft which can be done in softwares like Solid Works, Pro/E, CATIA-V5; of which mostly Pro/E is used. The second step is analyzing the model of crankshaft which is mostly done in ANSYS software and sometimes in CATIA-V5.

Also, according to crankshaft vibration analysis carried out before:

It can be concluded that as per the analysis done in the literatures till now, it is confirmed that the area at the center of the crankpin is where maximum deformation occurs and the maximum stress appears at the fillet areas of the crankshaft. Hence, it can be said that care should be taken at these particular areas of the crankshaft while designing or manufacturing it. Also, reducing the weight of the crankshaft can improve its durability.

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