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## Crankshaft Design Methodology for Diesel Engines

K.Pandiyan,<sup>1</sup> Dr. Ashesh Tiwari<sup>2</sup>

Final Year ME Student, Department of Design & Thermal Engineering, Department of Mechanical Engineering,  
Institute of Engineering and Technology, Devi Ahilya Vishwavidyalaya, Indore, M.P, India<sup>1</sup>

Professor & Head, Department of Mechanical Engineering, Institute of Engineering and Technology, Devi Ahilya  
Vishwavidyalaya, Indore, M.P, India<sup>2</sup>

**ABSTRACT:** The crankshaft is one of the most critically loaded components as it experiences cyclic loads in the form of bending and torsion during its service life. Its failure will cause serious damage to the engine so it's important at the time of design to verify fatigue strength and torsional vibration and physical validation on test bed as well as on field vehicles. More challenges in crankshaft design due to increasing vehicle payloads, lower weight requirement, higher efficiency and longer durability life. This paper will give an overall guideline for the student and industry engineers for designing the crankshaft which can serve the longer durability life without any failures.

**KEYWORDS:** Fatigue strength, Transient analysis and Damper

### I. INTRODUCTION

A crankshaft is part of an engine four-bar mechanism that rotates as the piston moves up and down. The first bar is the connecting rod, the second bar is the crankshaft from the crank pin to the main journal, the third bar is the engine block, and the fourth bar is the piston. The crankshaft turns around and the upper end of the connecting rod oscillates up/down while the lower end rotates with the crankshaft. The purpose of the four-bar mechanism is to convert the up and down motion of the piston into the rotating motion of the crankshaft.

A rod journal, or crank pin, is the area of the crankshaft that the connecting rod attaches to. The surface is highly polished because it makes up part of the bearing system.

A main journal is the area of the crankshaft that attaches to the block. The main journal cooperatively makes up the rotating axis of the crankshaft. The surface is highly polished because it also makes up part of the bearing system. Arms serve as a connection between a main and rod journal or a rod journal to rod journal connection.

Counterweights are attached to the arm and serve as counter balance mass to counteract the unbalance forces created by the rod journals, arms, connecting rod and the piston assembly.

A crankshaft bay includes all elements of the crankshaft between two adjacent main journals.

### II. CRANKSHAFT DESIGN PROCEDURE

The below is brief guideline for designing the crankshaft. To start the crankshaft design first all the basic engine details are required. Basic engine details like bore, stroke, engine configuration, compression ratio, bore centre distance and connecting rod length will decide the basic shape of the crankshaft and one can able to decide the crankpin and main journal locations. General crankshaft design procedure is as follows.

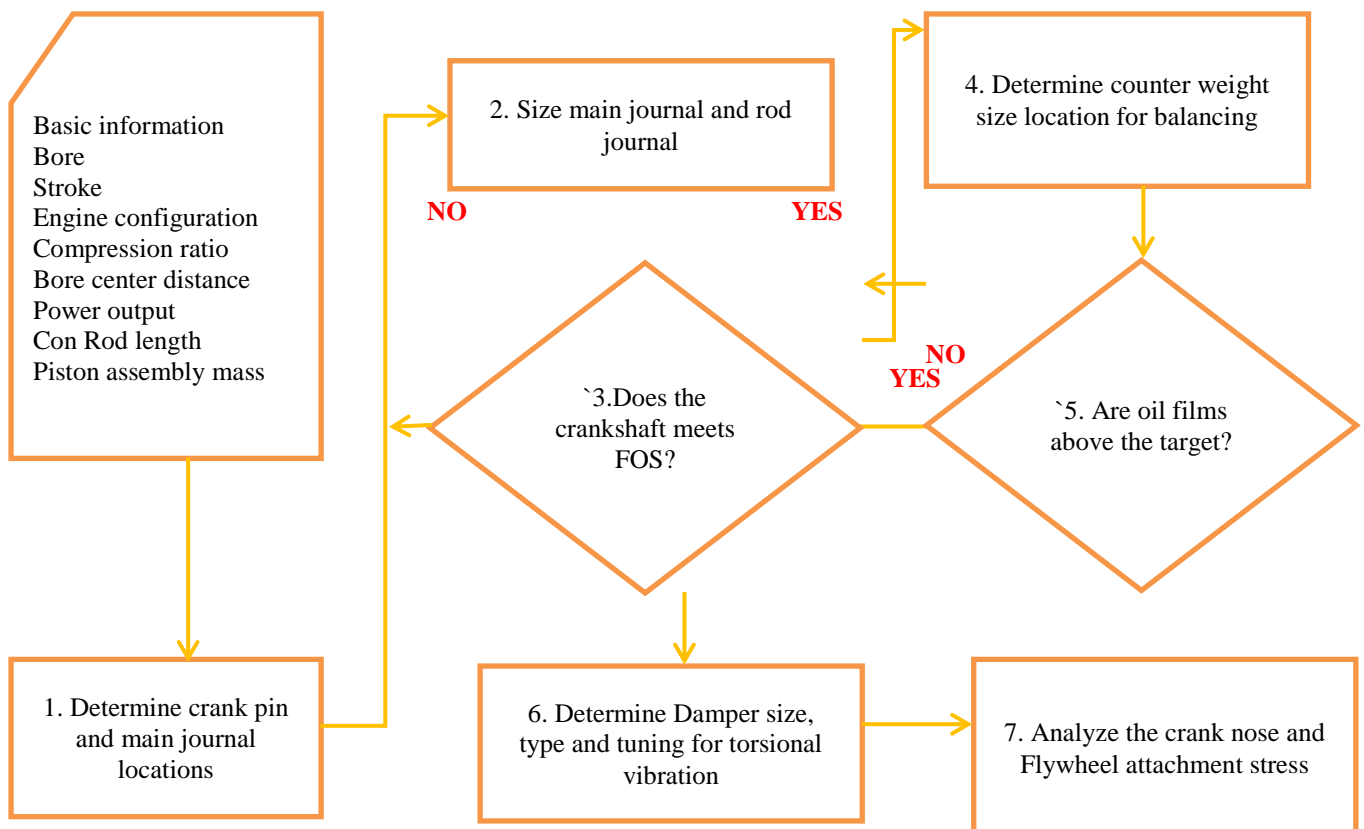


Fig 1 Crankshaft design flow chart

### III. CRANKSHAFT DESIGN CONSIDERATIONS AND PROPOSITIONAL DIMENSIONS

The present design consideration is to increase the stiffness of the crankshaft and reduce its overall length by incorporating narrow journals of large diameter. For the required wall thickness and coolant passages, the minimum cylinder centers can be around 1.2 times the cylinder bore diameter for an engine having its stroke equal to nearly the bore. The maximum diameter of the big-end for the connecting-rod assembly that can pass through the cylinder is 0.65 times

of the bore. The proportions of the crankshaft are as follows:

- Cylinder bore diameter** = D
- Cylinder Centre distance** = 1.20 D
- Big-end journals diameter** = 0.65 D
- Main-end journal diameter** = 0.75 D
- Big-end journal width** = 0.35 D
- Main-end journal width** = 0.40 D
- Web thickness** = 0.25 D
- Fillet radius of journal and webs** = 0.04 D

To increase the fatigue life of the shaft, the fillet radius between journals and webs should be as large as possible but not less than 5% of the journal diameter. The overlap between the diameters of the big-end crankpin and the main-end journal depends on the length of the stroke i.e. the crank-throw. A long-stroke engine has very little overlap, requiring thicker web sections, and a short-stroke engine has considerable overlap which strengthens the shaft.

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Collars are machined on the webs adjacent to the journals to accurately align the crankshaft and the bearings with the correct amount of side-float and, if necessary, to absorb the crankshaft end-float. Most crankshaft dimensions are such that the nominal stresses in the material under operating conditions do not exceed 20% of the tensile strength in bending and 15% in torsion. Crankshaft journals are ground to provide a surface finish better than 0.5 urn, to minimize bearing wear.

Crankshafts normally have either integral or attachable counterweights. These counterweights counteract the centrifugal force created by each individual crankpin and its webs as the whole crankshaft is rotated about the main-journal axis. In absence of the counterweights, the crankpin masses tend to bend and distort the crankshaft causing excessive edge-loading in the main bearings. Therefore, each half crank-web is generally extended in the opposite direction to that of the crankpin, to counterbalance the effects of the crankpin.

## IV. CRANKSHAFT MATERIALS

Crankshafts materials should be readily shaped, machined and heat-treated, and have adequate strength, toughness, hardness, and high fatigue strength. The crankshaft is manufactured from steel either by forging or casting. The main bearing and connecting rod bearing liners are made of Babbitt, a tin and lead alloy. Forged crankshafts are stronger than the cast crankshafts, but are more expensive. Forged crankshafts are made from 38MnS6 or similar type steel. Forging makes a very dense, tough shaft with a grain running parallel to the principal stress direction.

### Crankshaft failure modes

A crankshaft consists of several parts such as the crank-web, crank-pins and journals and therefore there could be a fault with either of these parts. There could be various modes of a crankshaft during service. The failure could be due to crack developed in any section such as the web, pin or journal and the piece could get completely broken in the worst case. Also there could be a case of slip shrinks which would be problematic.

Apart from that there could be web failure due to fatigue which is due to the presence of deflections which are beyond permissible limits and hence cause bending of the crankshaft causing fractures due to fatigue.

There are other defects which might develop in the crankshaft but are not directly related to the forces on it and such defects include corrosion, scoring and ovality of the cross-section of the crankshaft

### Reasons for failure of crankshaft

**Fatigue Failure:** Majority of steel crankshaft failure occurs because of fatigue failure, which may originate at the change of cross-section such as at the lip of oil hole bored in the crankpin.

**Failure due to Vibration:** If the engine is running with heavy vibration especially torsional vibration, it may lead to crack in the crankpin and journal.

**Insufficient lubrication:** If the lubrication of bearing in the crankshaft is starved, it may lead to wipe out of the bearing and failure of the crankshaft

**Over Pressurized Cylinder:** It may happen that there is hydraulic lock (water leakage) inside the liner and due to extreme pressure the crankshaft may slip or even bent (if safety valve of that unit is not working).

**Cracks:** Cracks can develop at the fillet between the journal and the web, particularly between the position corresponding to 10 o'clock and 2 o'clock when the piston is at T.D.C.

Examples of crankshaft failures:

Below are the few examples of bending and torsional fatigue failures.

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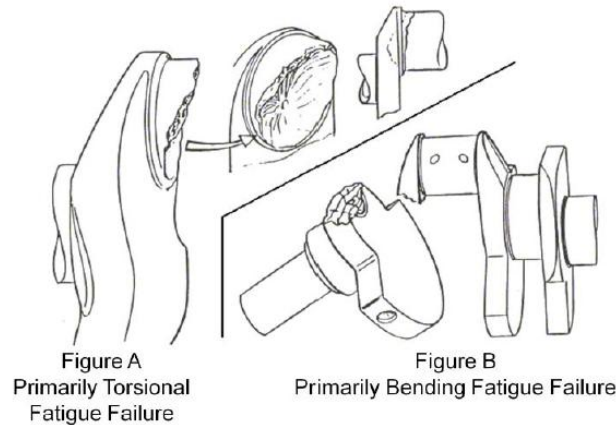


Fig 2 Different fatigue failures

## V. VERIFICATION AND VALIDATION METHODS

Fatigue strength of crankshaft against working load is very important to avoid the durability failures. This can be evaluated by different verification methods using finite element analysis. Single throw FEA is the first step to find the stress and fatigue factor of safety.

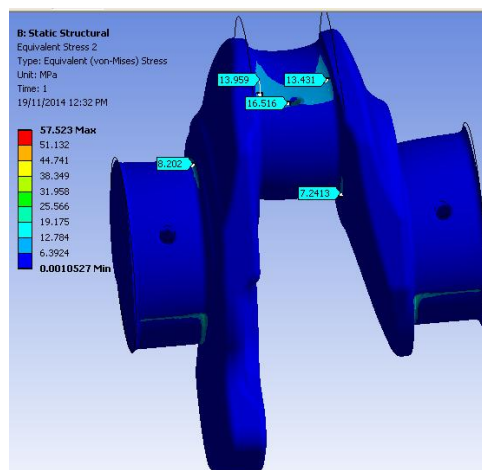


Fig 3 FEA analysis

In addition to finite element analysis physical validation is also required to confirm the crankshaft life. The physical validation method require prototype crankshaft. Sometime whole crankshaft manufacturing is an expensive one also without good confidence no point in investing for the whole crankshaft. Single throw for one cylinder can be manufacture first and the same can be validated on the test rig of life estimation and to finalize on fillet radius, crank pin diameter, main journal diameter and overlap between pin and main journal.

The set up for single throw life estimation is looks as below.

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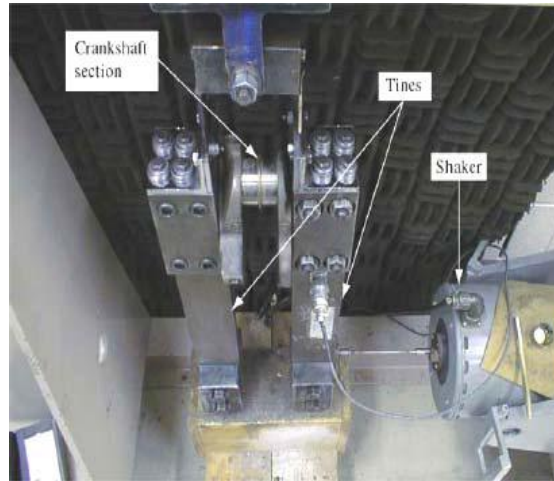


Fig 4 Fatigue life estimation test rig

Transient analysis is the method for the crankshaft dynamic analysis. In the dynamic analysis one complete cycle load is applied on crankshaft with respect to the firing order sequence. This provides the stresses very close the working condition stress level. For doing the same complete crank train assembly is taken into account along with damper and flywheel assembly. Meshing is done through hyper mesh and solver is the Nastran. The expected result will be as below.

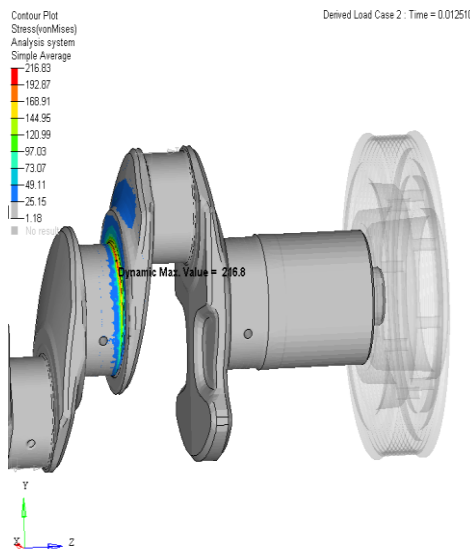


Fig 5 Transient analysis

Further crankshaft can be refined for torsional vibration by selecting the suitable damper. There are two types of dampers are available one is the rubber damper and the other one is the viscous damper. Viscous damper is expensive compare to the rubber damper. Torsional vibration control point of view viscous damper is more efficient than the rubber damper.

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To select the suitable damper torsional vibration on the engine is to be known. This is possible by measuring the torsional vibration at different orders. Acceptable limit is taken based on the experience in the range of 0.14 to 0.2 degrees. In case measured values are exceeded then the suitable damper selected through different test to control the torsional vibration with in the acceptable limit



**Fig 6 Damper to control torsional vibration**

## VI. RESULTS AND OBSERVATIONS

Crankshaft stresses are within the fatigue limit for 160 bar peak firing pressure. The fatigue strength of the material is 286 MPa. Forged steel material 38MnS6 is the material suitable for the high cylinder pressure conditions. To control torsional vibration, noise and overall engine vibration damper is required for the crankshaft at front end.

### Classical method calculation:

Crank pin fillet stress is 232.6 MPa. Stress values are higher due to the fact reaction point is considered center of the main journals.

### Static FEA results:

Crank pin fillet stress is 118.9 MPa.

### Tansient analysis stress results

Location	Stress MPa	Limit MPa	Remarks
Main Bearings (1,2,3,4 & 5)	226-236	286	Safe
Crankpins 1,2,3 & 4)	120	286	Safe

## VII. CONCLUSIONS

- Hand calculation is the first step to verify the crankshaft strength. Stress levels are within the fatigue limit for the bending load.
- Single through FEA analysis results are correlates with hand calculation.

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- Single through pulse test is important for taking a decision on investing the tooling for the full crankshaft.
- Transient analysis results are within the limit for both main journal and crankpin fillet radius.
- Torsional vibration measurement results are important information to conclude on damper requirement. Dampers are controlling torsional vibration and due to this engine overall vibration level reduced. In turn engine over all vibration reduction helped to reduce the noise.
- Crankshaft with 38MnS6 material is safe for 160 bar peak cylinder pressure operation without any failure in both bending and torsion.

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