Module 2 : Dynamics of Rotating Bodies; Unbalance Effects and Balancing of Inertia Forces; Field Balancing and Balancing Machines.

Lecture 4 : Rotor dynamics problems; Static and dynamic unbalance

Objectives

In this course you will learn the following

- Some interesting issues in rotor dynamics
- Types of unbalance viz., static and dynamic
- Balancing technique for achieving static balance

In the previous lecture we looked at a simple rotor wherein the disc was centrally located on the shaft and we studied the effect of unbalance. Now we will try and gain an appreciation of some more interesting problem situations in the field of rotor dynamics.

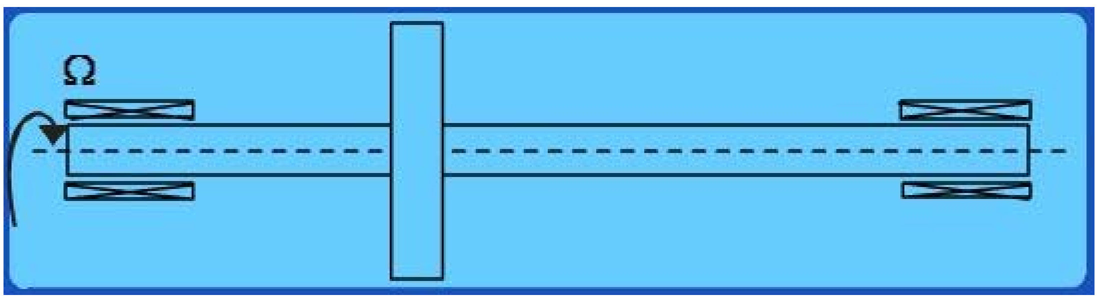

Fig 2.2.1 An offcenter Rotor

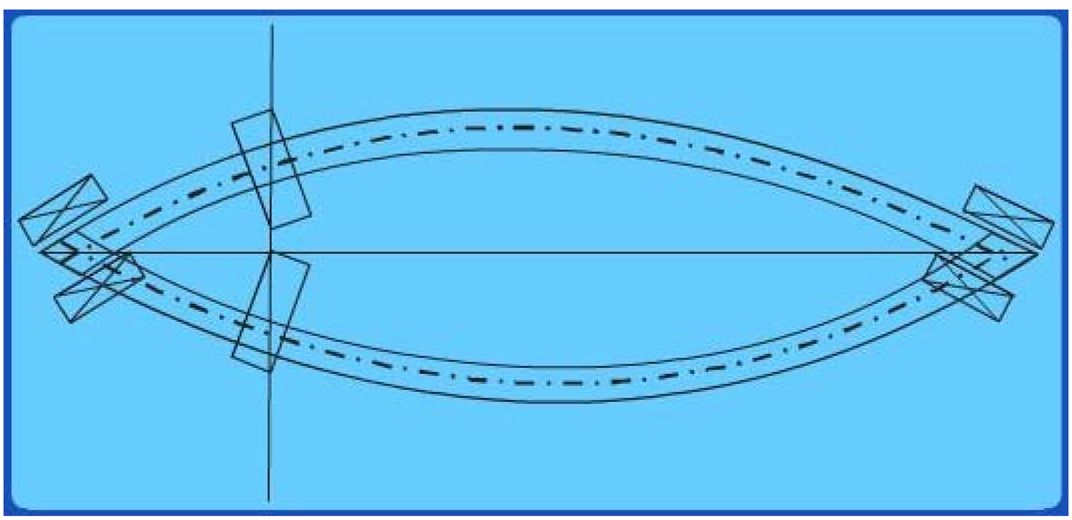

Fig 2.2.2 Two Position of the rotor

Consider the shaft system shown in Fig 2.2.1, wherein the disc is located at a point away from the mid-length of the shaft. Fig. 2.2.2 shows two positions and the point of interest is the orientation of the disc. As per Euler-Bernoulli beam bending theory, a plane cross-section remains plane and normal to the neutral axis even after bending. Thus we observe that the disc has actually rotated about an axis perpendicular to the plane of the figure. The moment of inertia of the disc therefore plays a significant role in this rotation of the disc and has an affect on the dynamics of the rotor-shaft system.

The location of the disc on the shaft and the particular shape of deformation of the shaft determine the extent of the influence. As shown in Fig 2.2.3, the steeper the variations in the slope of the shaft in the deformed shape, the larger the rotations of the disc and hence the larger the influence. Thus an accurate analysis of the dynamics of the rotor will need to take into account this influence.

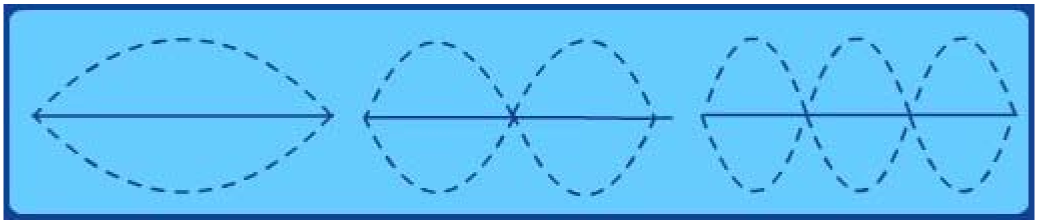

Fig 2.2.3 Some typicalmode shapes f deformation

We have so far assumed that the bearings are stiff. A normal hydrodynamic bearing, however, has finite stiffness and damping. Also, these may not be the same in all directions. A typical model of a rotor in journal bearings is shown in Fig. 2.2.4. We need to take into account the general non-linear and anisotropic bearing stiffness/damping properties. Thus an accurate model of the entire system would become quite complex and will need advanced modeling techniques.

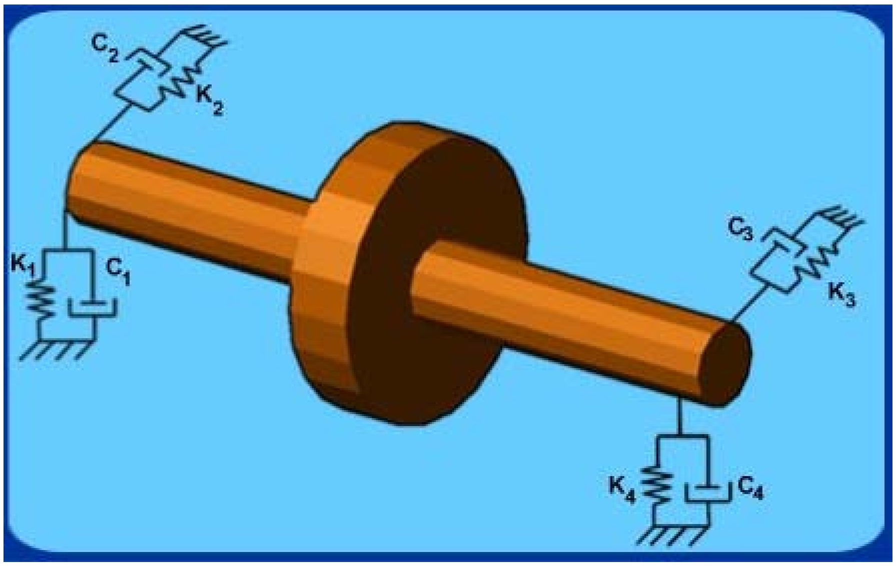

Fig 2.2.4 Model of a Rotor-Bearing system

When we consider a typical rotor of a turbine or compressor it is likely to have multiple stages and in each stage several blades attached around the circumference of the disk. A single stage is schematically shown in Fig. 3.2.5. Several blades are sometimes grouped together using “lacing wires”. Also, not all the blades in a stage will be exactly identical due to various manufacturing process variations etc. The individual blades are of aero-foil cross-section and are twisted / tapered and attached at a stagger angle to the disk. Thus the dynamics of the complete bladed-disk unit is quite a challenging problem.

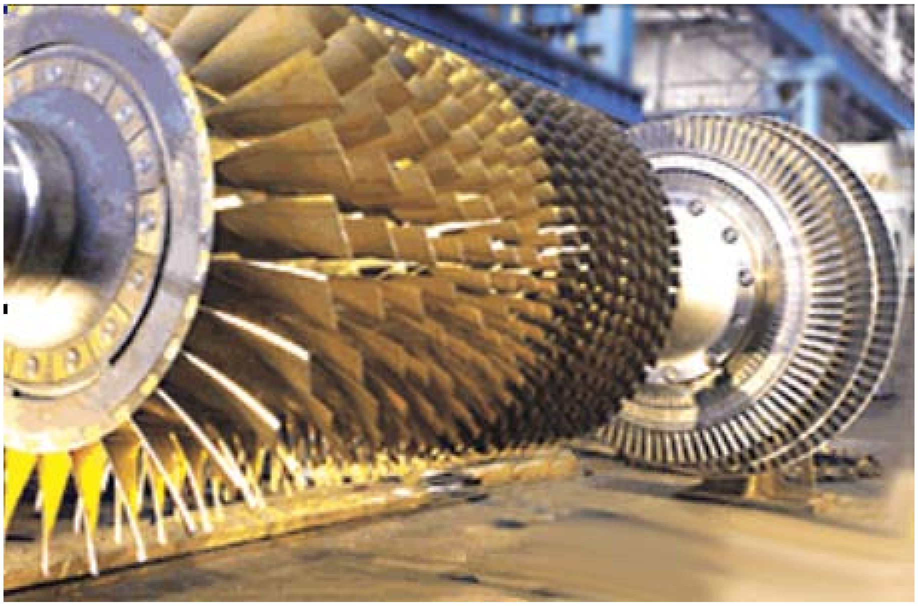

Fig 3.2.5

Thus you will appreciate that the field of rotor-dynamics offers many practically significant and theoretically challenging research problems. We will however restrict our discussion to just the problem of achieving "balance".

A rotor can in general have two types of unbalance viz., "static" and "dynamic". It is of course to be appreciated that practical systems will all have dynamic unbalance only and considering it as static unbalance is a "good-enough" approximation for some cases.

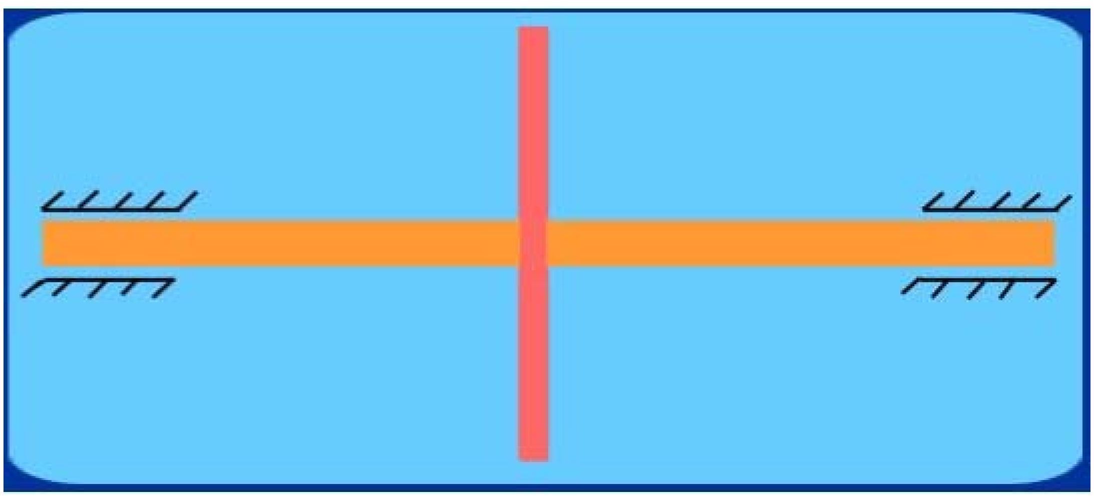

Fig 2.2.6 A thin Rotor Disc - Illustration of Static Unbalance

If the rotor is thin enough (longitudinally) as shown in Fig. 2.2.6, the unbalance force can be assumed to be confined to one plane (the plane of the disc). Such a case is known as "static" unbalance. Such a system when mounted on a knife-edge as shown in Fig. 2.2.7, will always come to rest in one position only – where the centre of gravity comes vertically below the knife-edge point. Thus in order to "balance out", all we need to do is to attach an appropriate "balancing mass" exactly 180^0 opposite to this position.

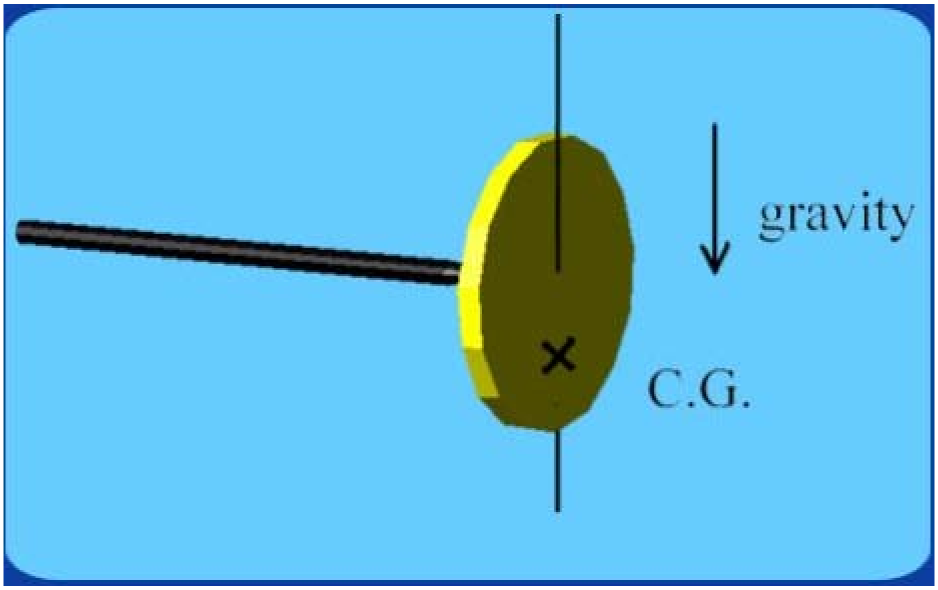

Fig 2.2.7 Thin Rotor on a knife edge - Illustration of Static Unbalance

Thus we first mount the disc on a knife edge and allow it to freely oscillate. Mark the position when it comes to rest. Choose a radial location (180^0 opposite to this position) where we can conveniently attach a balancing mass. By trial and error the balancing mass can be found out. When perfectly balanced, the disc will exhibit no particular preferred position of rest. Also when the disc is driven to rotate by a motor etc., there will be no centrifugal forces felt on the system (for example, at the bearings). Thus the condition for static balance is simply that the effective centre of gravity lie on the axis.


Fig 3.2.8 A Case of Dynamic Unbalance

Consider the rotor shown in Fig. 3.2.8. It is easily observed that mass distribution cannot be approximately confined to just one plane. So unbalance masses and hence unbalance forces are in general present all along the length of the rotor. Such a case is known as “dynamic unbalance”.

The fundamental difference between static and dynamic unbalance needs to be clearly appreciated.

When a rotor as shown in Fig. 3.2.8 is mounted on a knife edge and allowed to oscillate freely, it too may come to rest in one particular position all the time – the position corresponding to the resultant unbalance mass (centre of gravity) vertically below the knife edge. We could, like earlier, mount an appropriate balance mass exactly 180^0 opposite to this position. It would then have no preferred position of rest when mounted on a knife-edge. Thus effective center of gravity lies on the axis.

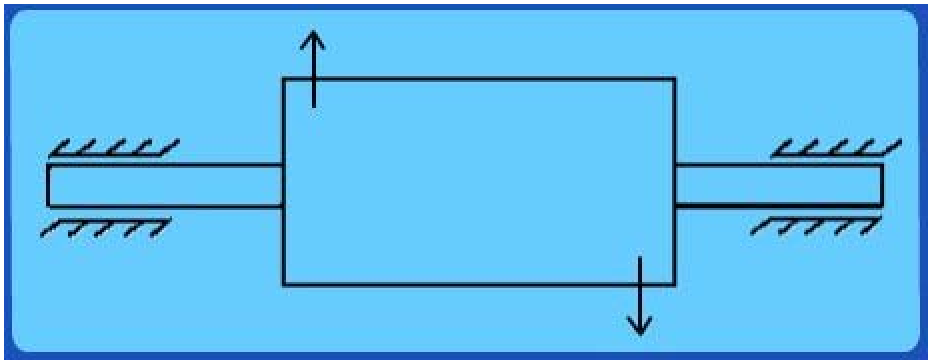
Fig 3.2.9 Example of unbalance masses leading to unbalance force that for a resultant couple because of axial.

However, when mounted in bearings and driven by a motor etc., it could still wobble due to the unbalanced moments of these forces as shown in Fig. 3.2.9. This becomes apparent only when the rotor is driven to rotate and hence the name “dynamic unbalance”. Thus it is not, in general, sufficient to do just static balance but achieving good dynamic balance is more difficult. We will discuss one important method of achieving dynamic balance in the next lecture.

Recap

In this lecture you have learnt the following

- Some interesting issues in rotor dynamics

- Static vs dynamic balance