UNIT 5

ME 401

Balancing of linkage

Outline

- Unbalance
- Balance Standards
- Balancing
- Balance Machines
- Misalignment

Unbalance

- Perfect Balance
- Rigid Rotor Unbalance
  - Static Unbalance
  - Dynamic Unbalance
- Flexible Rotor Unbalance
  - Critical Speed
  - Mode Shape

Perfect Balance

- A ***rigid rotor*** has a uniform speed of rotation about one of its three principal inertia axes.
- The ***rigid rotor*** rotates about the axis of rotation without wobbing; i.e., the principal axis coincides with a line fixed in space.

Rigid Rotor Unbalance

- Static Unbalance (Static Balancing)
- Couple Unbalance (Two-Plane Balancing)
  - Static Balance + Nonzero moment about center of mass when rotates
  - Tilting of the principal inertia axis about the shaft axis at the center of mass
- Dynamic Unbalance (Two-Plane Balancing)
  - Static Unbalance + Couple Unbalance
  - The principal inertia axis inclined to the geometric shaft axis

Rigid Rotor Unbalance

- Definition of Unbalance
  - ***M***: mass of a thin disc (unit: g)
  - ***m***: unbalance mass (unit: g)
  - ***r***: distance between the unbalance mass and axis of rotation (unit: mm)
  - ***e***: eccentricity, specific unbalance (unit: mm)
  - ***F***: centrifugal force (unit: μN)
  - **ω**: speed of rotation (unit: rad/sec)

Rigid Rotor Unbalance

$$F = mr\omega^2$$

$$= Me\omega^2$$

- Unbalance (u):

$$u = mr$$

- Specific Unbalance (e):

$$e = \frac{mr}{M}$$

Flexible Rotor Unbalance

- Critical Speed
- Mode Shape

Effects of Unbalance

- Synchronous with rotation speed
- Radial in the line of action
- Vector quantities
- Result of a discrepancy between the geometric- and mass-symmetries of a rotor

Sources of Unbalance

- Dissymmetry
- Non-homogeneous material
- Distortion at service speed
- Eccentricity
- Misalignment of bearing
- Shifting of parts due to plastic deformation of rotor parts
- Hydraulic or aerodynamic unbalance (cavitation or turbulence)
- Thermal gradients

Balance Standards

- ISO 1940 (VDI 2060)
  - Balance Quality of Rotating Rigid Body
  - Define the acceptable residual unbalance to the maximum service speed of the rotor
  - $G = e\omega$
    - G: Quality Grade
    - e: Specific Unbalance (mm)
    - ω: speed of rotation (unit: rad/sec)

Balance Standards

- ISO 2372 (VDI 2056)
  - Mechanical vibration of machines with operating speeds from 10-200 rev/sec

Balancing

- Rigid Rotor Balancing
  - Static Balancing
    - Static Balancing Machines (see next topic)
  - Single-Plane Balancing
    - Three-Point Method (Siebert’s Construction)
    - Single-Point Phase-Angle Method
  - Two-Plane Balancing
- Flexible Rotor Balancing

Three-Point Method (Siebert's Construction)

- Equipment: Vibration Meter and an Accelerometer
- Procedure:

1. The initial unbalance is measured. (V_0)
2. A trial mass is used to introduce a known unbalance by attaching it to the rotor at the same radius to be used for the final correction mass.
3. Three test runs are carried out with the trial mass placed at 0^o, 120^o, 240^o on the rotor. (V_1, V_2, V_3)
4. Geometrically, Siebert construction can be used to evaluate the correction values.
5. Three vectors of equal length, corresponding to initial unbalance V_0, at 0^o, 120^o, 240^o respectively, are drawn out from the origin.

Three-Point Method (Siebert's Construction)

6. Vectors corresponding to V_T (0^o), V_T(120^o), V_T(240^o) are constructed by centering a compass point on each of the V_0 vectors in turn: the point of intersection of these arcs enables the vectors corresponding to the trial mass alone to be constructed.
7. The correction mass can be calculated directly.

Single-Point Phase-Angle Method

- Procedure:
  1. An initial reading of vibration amplitude, $|V_0|$, and phase angle, α_0 (with reference to a fixed point on the rotor) are obtained.
  2. Machine is stopped and a known trial mass M_T is fixed to the rotor at some arbitrary position. Running the machine at the same speed as before yields a new vibration amplitude, $|V_1|$, and phase angle, α_1 enabling a vector diagram to be constructed directly.
  3. The difference $(V_1 - V_0)$ represents the effect of trial mass, M_T, on the measured vibration.

Single-Point Phase-Angle Method

4. The size of the correction mass is given by

$$M_c = \frac{|V_0|}{|V_1 - V_0|} M_T$$

   placed at an angle α_c to counteract V_0.

5. Where non-linearities, or incorrect choice of trial mass, do not allow acceptable residual unbalance to be achieved in the first run, it may be necessary to repeat the procedure.

Two-Plane Balancing

- Procedure:
  1. The initial condition of unbalance is assessed measuring $|V_{10}|$, α_0 and $|V_{20}|$, β_0. (β signifies phase in the 2nd measuring plane.)
  2. A trial mass M_{T1} is placed on correction plane 1, measuring $|V_{11}|$, α_1 and $|V_{21}|$, β_1.
  3. A trial mass M_{T2} is placed on correction plane 2, measuring $|V_{12}|$, α_2 and $|V_{22}|$, β_2.
  4. It can be seen that:

     $(V_{11} - V_{10})$: effect of M_{T1} at measuring position 1.

     $(V_{12} - V_{10})$: effect of M_{T2} at measuring position 1.

     $(V_{21} - V_{20})$: effect of M_{T1} at measuring position 2.

     $(V_{22} - V_{20})$: effect of M_{T2} at measuring position 2.

Two-Plane Balancing

5. To balance the rotor, correction masses should be placed in planes 1 and 2 to generate vibrations equal in magnitude but opposite in direction to V_{10} and V_{20}.

$$\begin{pmatrix} M_{c1} \\ M_{c2} \end{pmatrix} = \begin{bmatrix} \dfrac{V_{11}-V_{10}}{M_{T1}} & \dfrac{V_{12}-V_{10}}{M_{T2}} \\ \dfrac{V_{21}-V_{20}}{M_{T1}} & \dfrac{V_{22}-V_{20}}{M_{T2}} \end{bmatrix} \begin{pmatrix} -V_{10} \\ -V_{20} \end{pmatrix}$$

Flexible Rotor Balancing

- Procedure:
  1. The rotor is rotated at a speed less than ½ the rotor's first flexural critical speed and balanced using a rigid-rotor balancing technique. Balancing corrections are performed at the end planes to reduce the original amount of unbalance to 3 or 4 times the final balance tolerance.
  2. Correction for the First Flexural Mode (V Mode).
  3. Correction for the Second Flexural Mode (S Mode).
  4. Correction for the Third Flexural Mode (W Mode).
  5. ……..
  6. Final Balancing at Service Speed

Balance Machines

- Gravity Balancing Machines
  - Non-rotating Balancers
  - Static Balancing
- Centrifugal Balancing Machines
  - Static and Dynamic Balancing
  - Soft-Bearing Balancing Machines
  - Hard-Bearing Balancing Machines