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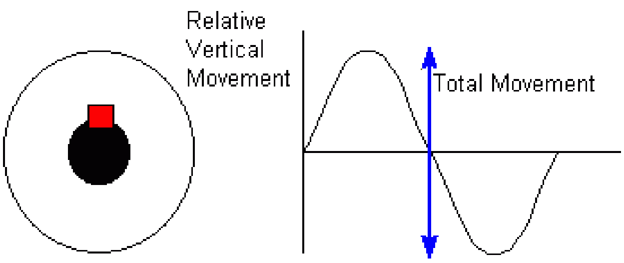
Home Knowledge

Maintenance Management

Vibration Analysis

Vibration Analysis

Description of vibration



Shown in the diagram is the representation of a shaft with an out of balance in the form of a key. The graph plots the relative vertical displacement of a point on the disc.
The total vertical movement is called the Peak to Peak Displacement of the vibration. This is an indication of the amount of lateral movement of the machine and is a good indication of the amount of out of balance in a machine when the value is compared to a standard for that machine. This parameter is often used when balancing.
The Vibration Velocity is the speed of movement of this point, being highest as the point passes through its at rest position. It gives a good guide to the amount of energy being generated by the vibrating object. This energy usually results in wear and eventual failure. The amount of energy is proportional to the square of the velocity of vibration. Velocity, being a good indication of the amount of wear taking place in a machine is a used exclusively in monitoring systems.
For analysis purposes the r.m.s value is used.
For very low speed machines where the velocity is low the displacement may be used instead.
The Vibration Frequency is the time taken to complete one cycle. The shaft above is said to have a fundamental frequency equal to the shaft rotational velocity i.e. R.P.M / 60 = Fundamental frequency = 1 / Periodic time
There is a formula for working out the frequency that a particular vibration is occurring from knowing only the displacement and the velocity.
Frequency = 0.45 x Vibration Velocity (mils/sec r.m.s)/ Vibration Displacement (mils peak to peak)
The equation is true only when the majority of the vibration occurs at one frequency. In reality machines vibrate in a much more complex way with vibration occurring at several frequencies. By analysis of the frequency at which each of the vibrations are occurring it is possible to ascertain whether they are being generated from with the or externally. By further analysis it is possible to locate the source of vibration within complex machinery.

Vibration phase can be defined as the angular relationship between the positions of maximum vibration and some fixed point on a rotating shaft at any instant. It is useful during balancing.

Vibration measurement units

There are three different ways of expressing vibration measurements

- Peak to Peak
- Half Peak (or Peak)
- Root Mean Square

they are related as follows
R.M.S. =Peak to Peak/2.83
Half Peak Values = Peak to Peak/2
Units may be in mils (1x 10^{-3} inches) or microns (1x 10^{-3} millimetres) and they may be converted as follows 1 mil =25.4 microns

Causes of vibration

Typical causes could be

- Out of balance
- Misalignment
- Damaged or worn bearings
- Damaged or worn teeth
- Resonance, loose components
- Bending or eccentricity
- Electromagnetic effects
- Unequal thermal effects
- Aerodynamic forces
- Hydraulic forces
- Bad belt drives
- Oil whirl
- Reciprocating forces

The great majority of the above create a vibration at a multiple of the fundamental. The Vibrations source identification table allows identification of the cause.

Sequence of analysis

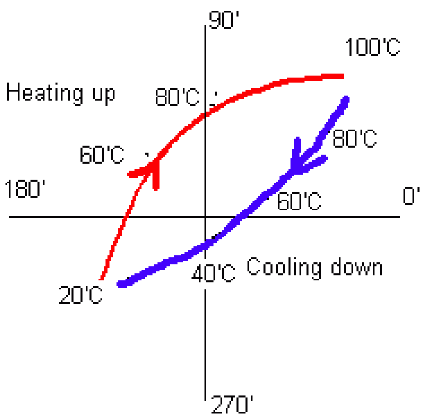
1. Assemble equipment
2. record operational parameters of machine- lubricating oil temperature, load, history of mal operation, work done
3. Run machine until it reaches normal operating temperature
4. Take readings at designated points. Analyse frequency of any high readings
5. If possible measure vibration at different speeds
6. Note changes in temperature, load etc. during measurement period
7. If possible double check readings
8. Determine source of vibration using identification table
9. Remedy fault

Additional information can be gained by measuring vibration of the shaft itself. This may be done using a Teflon tipped pick up or a piece of hardwood.

Causes of vibration other than initial out of balance

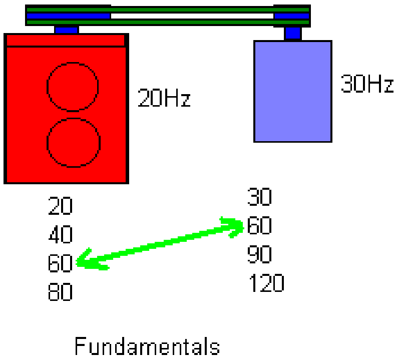
- Non-periodic erratic vibrations can often be sourced to damaged or worn anti friction bearings. Where displacement of inner and outer race occurs then axial vibration at fundamental can occur. If the bearing is not concentric to the shaft then a vibration occurs as an out of balance
- Where a moving component on a rotating member occurs an erratic fundamental frequency occurs. Balancing will only give temporary relief

and indeed may lead to a worsening of the situation
- Synchronous oil whirl occurs when the oil whirl in a bearing is at the same frequency as the fundamental. Analysis over a period will find a steadily worsening vibration which will begin to reduce if the speed of the machine is dropped, and then increase again when brought back to original speed. In this case the bearing clearance may be too large
- Half speed oil whirl is indicated by a superimposed wave form at half fundamental on the total wave form. Varying oil temperature and pressures normally rectify but it may be necessary to increase bearing load by reducing bearing surface
- Shafts may sometimes bend due to thermal asymmetry. Vibration will vary with temperature. If unequal thermal effects are present then they may be determined by taking displacement and phase measurements during a set of controlled 'heating up' and 'cooling down' periods. If



Thermal effects may occur due to the following reasons.
1. Non-homogenous forging of the rotor causing uneven bi-metallic expansion
2. Uneven machining of the rotor forging
3. Parts of the rotating element is restrained from expansion
4. Friction effects due to parts rubbing
5. Uneven ventilation

Compromise or thermal balancing may be used to help alleviate the problem but these should only be carried out by specialised personnel
Double frequency vibration can have many different sources such as
- Non-isotropic characteristics of a rotor or shaft e.g. grooves, key ways, slots etc. causing the shaft to have two perpendicular stiffness' resulting in two cyclic deflections for one complete revolution. This can only be remedied by cutting two slots to even the stiffness.
- Electromagnetic effects most significant in the laminations. Only present when energised, increasing pressure on laminations can cure
- Machines with separate bearing housings which are not aligned can have vibration at 1,2 or 3 times fundamental. Indicated by large axial vibration component at pedestal.
- Bad belt drives give 1,2,3,4 harmonics which may not remain constant. Where the belt drive gives a speed change between driver and driven machines vibration can occur at a frequency corresponding to some multiple of both fundamental frequencies.



- Reciprocating parts can give multiple fundamental vibrations, only by redesign can this be cured, Diesel engine can vibrate at 2 x fundamental known as the forcing frequency caused y the action of the crank moving the piston rod. The travel of the piston is not entirely smooth and a slowing and speeding up occurs about the middle of the stroke and is governed by the ratio of crank throw to piston rod length. It may be counteracted by the use of balancers.
- Looseness

- Three per revolution vibrations
  - Sleeve bearing worn in a triangular fashion-unusual
  - Poor belt drives
  - Higher frequency vibrations can be caused by
    1. Badly mating or worn gears giving very high frequencies
    2. Aerodynamic and hydraulic forces will produce high frequency vibrations. If a fan is the source then the frequency will be at blade number x fundamental and may be caused by
       - Unequal pitch of blades giving unequal axial vibration
       - Blade vibrations as the blades operate at a resonant frequency
       - Pipework and ducting can cause gas or liquid flows to produce a vibration at resonance
       - Cavitation or oil pockets may produce high frequency resonant vibrations
       - Wheels on turbine spindles can cause vibration
  - Odd harmonics can sometimes be caused by worn components. Usually at fundamental the waveform may be erratic and irregular i.e. non- sinusoidal

Determination of rolling element bearing wear using vibration acceleration as the parameter

The condition of rolling element bearings can be accurately determined by taking measurements of acceleration in terms of 'g' peak.
Irregularities in newly fitted bearings lead to dynamic load and vibration detectable as accelerations in a vibration monitor. It is the magnitude and frequency span that determines the condition of the bearing. Accelerations due to a failing bearing will fall between 1 - 5kHz.

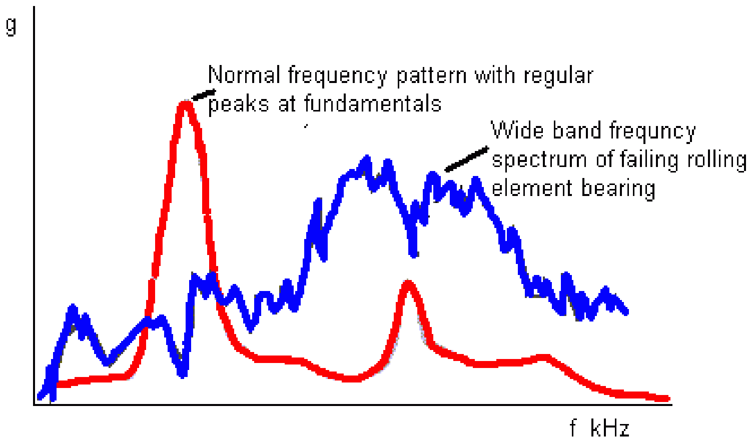
When judging the condition of a bearing it is important to take into account the speed at which it is running. Acceleration is proportional to the square of the rotational frequency. Therefore a slow running machine would give accelerations lower then a higher speed running machine for the same bearing condition.
The following table can be used as a rough guide.

State of rolling element bearing	Level of acceleration 'g' peak (in range 1 - 5 kHz)
Satisfactory	1
Bearing failing	2 -5
Renew bearing urgently	5+

This does not apply to journal, plain or sleeve bearings

Care must be taken with some the following machinery as they can naturally generate vibration in the 1 - 5 kHz range

- Gearboxes (i.e. gear teeth frequencies)
- High speed screw compressors - lobe passing frequency
- High speed turbines - blade passing frequency.
- Cavitation in pumps



If the peak appears to be isolated then other possible sources such as gear teeth should be investigated.
If the vibration occurs over a broad band then it is probably due to bearing failure.
Cavitation can be determined as the source by checking the locality of the source. Whether bearing housing or pump casing. Also the discharge valve may be partially closed which should reduce the cavitation and the vibration.

Method for assessing condition of rolling element bearing.

1. Measure radial acceleration at each bearing in vertical and horizontal directions and record the lowest value
2. evaluate condition of bearing against set levels
3. If over 1 (minimum that can be reliably analysed) then use harmonic analyser to check frequency range
4. put harmonic analyser in 'fine' mode and check spread of vibration, if over 500 Hz the probably bearing failure
5. Repeat as check '4' on velocity mode

The effect of main engine revolutions on vibration readings
Generally the increase in vibration will be small, their are some cases however were a noticeable rise occurs. This may be due to a flexible bed plate or harmonics.

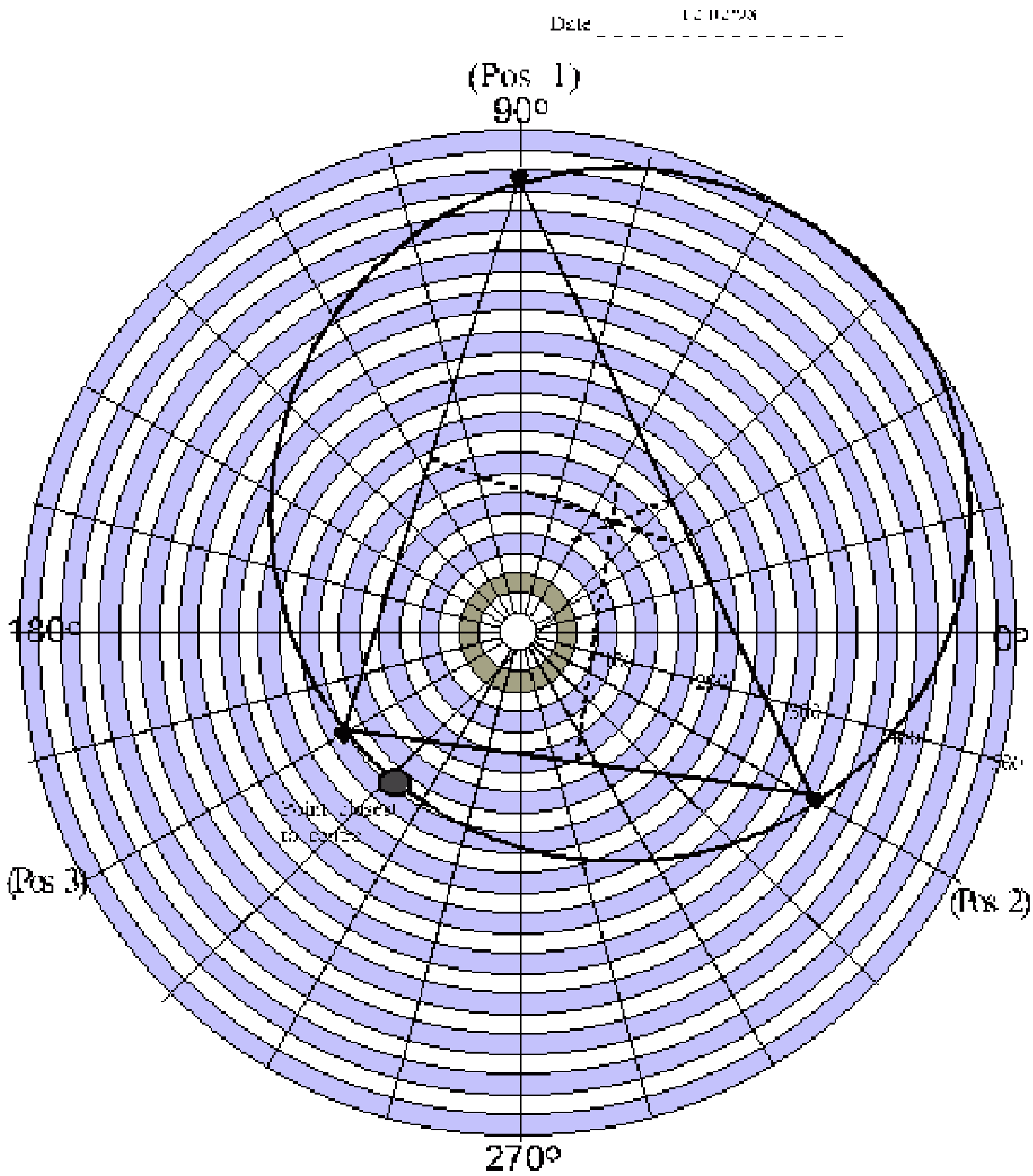
Balancing using a vibration analyser

The three point method of balancing.

1. Measure vibration and record (use analyser to ensure only fundamental frequency is used
2. Drill three holes in a suitable place, say in the motor fan. These should be as close to 120o as possible. Each hole should be labelled 1,2 or 3 corresponding to three angles of the polar diagram. Place the calibration weight, which should be small especially for high speed motors, in the three positions and take vibration readings from the same point
3. Plot the points on the polar diagram. Looking at the highest reading the scale of the polar diagram can then be determined.
4. Join the first point to the second point and bisect this line. Join the second point to the third point and bisect the line, etc.
5. From the points of bisection of the lines, draw perpendiculars so that they intersect.
6. Using the point of intersection as the centre, draw a circle to cut each of the plotted measured points. This circle indicates the level of vibration that can be made by moving the weight around the circle
7. The point at which the circumference of the circle is nearest to the centre of the polar diagram is the point at which the balance weight needs to be fixed
8. The amount of weight (ASSUMING THAT THE TRIAL WEIGHT WAS TOO SMALL) is given by;
9. Trial Weight x Initial Vibration Level / (Initial Vibration Level - Vibration Level At Best Position On Circle)

Example-Engine room supply fan	
Vibration velocity (mils)	Comment
300	Initial vibration
450	Trial weight in position 1
340	Trial weight in position 2
200	Trial weight in position 3

Final weight



Vibration source identification

Source	Freq	Magnitude	Remarks
Unbalanced Rotating Components	1 x F	Velocity and displacement highest in radial direction. Proportional to size of out of balance	Common cause of vibration due to dirt build up on rotating element or wear. In-Situ balancing following cleaning/repairs gives best results

Misalignment of coupling and bearings	2xF usual also 1&3F	Velocity and displacement large in axial directions	Common cause of vibration. Flex couplings should not be relied upon to make up misalignement
Damaged Ball / roller Bearings	High 5kHz	Acceleration level high in rolling element bearings. Distinguished by wide history	Often first component to show vibration though cause may be elsewhere
Work, Damaged or poor bearings	Very high, gear teeth x F	Use velocity measurement. Acceleration may be too high	Often vibration accompanied by noise
Resonance, Loose component	1&2 and Higher x F	Velocity and displacement can be very high. Big variation at joints	A common cause of vibration. Resonance readings may be reduced by strengthening foundations/bearings supports
Bending	1&2 x F	Velocity and displacement can be high. Often large in axial direction	Check shaft bend with clock gauges. Check shaft material correct for operating temperatures, no rubbing at seals
Electromagnetic effects in stator/rotor	Poles x F	Vibration disappears with power switched off	
Unequal thermal effects	1 x F	Varies with load	Fundamental problem not met often. Compromise balance sometimes helps
Hydrodynamic forces	Impeller blades x F	Velocity can be high if associated pipework resonant	Not common, stiffening pipework supports may help. Cavitation causes very high freq vibrations
Aerodynamic	Fan blades x F	Velocity high if support structure/casing resonant	No Common
Bad Belt Drives	Varing x F	Velocity erratic	Can be checked using stroboscope. Examine belts and pulley for wear
Oil Whirl	½ x F	Displacement and Velocity unstable and increasing with time. Can be very High	Can create alarming vibrations. Occurs on on high speed plain bearing machines.