PRINCIPLES OF OPERATION:

Centrifugal pumps are among the more versatile and widely used pieces of rotating mechanical equipment found today. Pumps are essential in almost all utilities services and power generation plants. It is estimated that pumps consume approximately 31% of rotating equipment electrical power used throughout industry. Pumps are a vital part of our lives on the planet today.

The basic principle of operation for a centrifugal pump is that a shaft mounted rotating impeller inside a housing (volute) imparts energy to the fluid being moved. Centrifugal pumps utilize centrifugal force (thus their name) to increase the velocity of the fluid as it passes through the impeller and exits at the tip or periphery of the impeller. This action converts mechanical energy (shaft torque) into kinetic energy by acceleration of the fluid to a higher velocity and pressure (potential energy).

PUMP PERFORMANCE:

Pumps follow basic laws of performance. These are useful in determining the effect of changes to the operating parameters and can help determine the cause of operational problems. These basic laws apply to most centrifugal pumps or pump systems.

1. Fluid flow (quantity) varies directly with the impeller rotating speed or diameter change.
2. Head generated (feet of head) varies with the square of the impeller tip speed (ft/sec)^2 divided by 64.4 (2g, ft/sec^2).
3. Horsepower varies directly with the volume and specific gravity of the fluid pumped.
4. Horsepower varies with the cube of a change in rotating speed or impeller diameter.

DETECTING PUMP PROBLEMS USING VIBRATION ANALYSIS:

Centrifugal pumps are subjected to operational forces generated by their operating speed, system head, pressure and piping arrangement. These operational forces cause forced vibration and may originate from the rotating parts or operating conditions (flow quantity, pressures, speed and arrangement). This vibration reduces the expected life of the pump bearings and other components.

SUMMARY OF COMMON PUMP VIBRATION PROBLEMS:
(Detected Using Vibration Analysis)

1. Cavitation:
   Cavitation typically generates random, higher frequency broadband energy, which is sometimes superimposed with blade pass frequency harmonics (multiples). Cavitation is a symptom of insufficient net positive suction head (NPSH). Cavitation results when the absolute pressure of the liquid at the pump impeller inlet approaches the vapor pressure of the liquid causing vapor pockets to form and collapse (implode) as they pass through the pump impeller. The collapsing of the vapor bubbles can be very destructive and may
damage the pump and impeller. When present, cavitation often sounds as if “marbles” or “gravel” are passing through the pump. The positive suction head required to correct suction cavitation is known as “NPSHR” (Net Positive Suction Head Required). This value is typically supplied by the pump manufacturer.

2. Pump Flow Pulsation:
   Pump flow pulsation is a condition that develops when a pump is operating near its shut-off head. The vibration in the time waveform will be sinusoidal. In addition, the spectra will still be dominated by 1X RPM and blade pass frequency. However, these peaks will be unstable, increasing and decreasing as the flow pulsation occurs. Pressure gauges on the discharge piping will fluctuate up and down. If the pump has a discharge swing check valve, the valve arm and counter-weight will bounce back and forth indicating unstable flow.

3. Bent Pump Shaft:
   Bent shaft problems cause high axial vibration with axial phase differences tending towards 180° on the same rotor. Dominant vibration normally occurs at 1X RPM if bent near shaft center, but at 2X RPM if bent near the coupling. Pump bent shafts are more common at or near the coupling. Dial indicators can be used to confirm a bent shaft.

4. Unbalance of Pump Impeller:
   Pump impellers should be precision balanced at the pump original equipment manufacturer (OEM). This is particularly important since forces due to unbalance greatly affect life of the pump bearings (bearing life varies inversely with the cube of imposed dynamic load). The pump may have a center-hung or an overhung impeller. If the impeller is center-hung, force unbalance often predominates over couple unbalance. In this case, highest vibration will typically be in the radial (horizontal and vertical) direction. The highest amplitude will be at the pump operating speed (1X RPM). In this case of force unbalance, the horizontal outboard and inboard phase will be about the same (+/- 30°), as will the vertical phase. In addition, there is usually about a 90° difference in horizontal and vertical phase on each pump bearing (+/- 30°). Center-hung impellers, by their design, have balanced axial forces on the inboard and outboard bearings. Elevated axial vibration is a strong indication of pump impeller obstruction by foreign objects causing the axial vibration typically at running speed to increase.

   If the pump has an overhung impeller, this will usually cause high 1X RPM in both the axial and radial directions. Axial readings tend to be in-phase and steady, whereas radial phase readings might be unsteady. Overhung rotors have both force and couple unbalance, each of which will likely require correction. Thus, correction weights will most always have to be placed in 2 planes to counteract both force and couple unbalance. In such cases, it will most always be necessary to remove the pump rotor and place it on a balance machine to balance it to sufficient precision since 2 planes will not normally be accessible in the field.

5. Shaft Misalignment:
   Shaft misalignment is a condition found on direct drive pumps where the centerlines of two coupled shafts are not coincident. Parallel misalignment is a condition where the shaft centerlines are parallel but offset from one another. The vibration spectrum often will show 2X higher than 1X and a 3X higher than normal with 180° out of phase across the coupling
in the radial direction. Angular misalignment will show high axial 1X with some 2X and 3X and a 180° phase shift axially across the coupling.

6. Pump Bearing Problems:
   Peaks (with harmonics) at nonsynchronous frequencies is a symptom of rolling element bearing wear. Short bearing life for pumps is typically the result of poor bearing selection for the application, such as excessive loads, poor lubrication or high temperatures. If the model number and manufacturer of the bearings are known, then the specific fault frequencies for the outer race, inner race, rolling elements and cage can be determined. These fault frequencies for such bearings are found within tables of most predictive maintenance (PdM) software today.

Centrifugal pumps have unique problems due to the operational conditions to which they are subjected that are not common to other machine types. These problems (or faulty conditions) can then generate some unique vibration spectra and time waveforms as outlined above. This article is intended to be a summary of common pump problems that vibration analysis can detect and identify. If reliability technicians obtain the proper vibration training they need that instructs them how to identify such problems and faulty operating conditions, they can utilize vibration analysis to identify each of the aforementioned problems (and other faults) before they result in failure. In turn, this will provide considerable savings in maintenance and operations expenditures if such problems are detected during early stages preventing catastrophic failure and causing loss of production and downtime. Studies have shown that centrifugal pumps are some of the most common machine types in use throughout virtually all industry types. The key to detecting and resolving such problems on centrifugal pumps is obtaining vibration analysis training from instructors who themselves have considerable vibration expertise, specifically with these particular machines. Technical Associates is one of several organizations offering vibration training on centrifugal pumps. Not only do they provide instruction on how to detect such faults using vibration signature analysis, but also how to apply time waveform analysis on these unique machine types. In addition, most training service providers offer vibration analysis certification through a written examination as confirmation of the student’s comprehension of the course material and the basics for detecting common pump problems using vibration analysis.

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