GRUNDFOS

# WHITE PAPER

## VIBRATION IN PUMPS

*by Steve Wilson*

Vibration will exist in all pumps and indeed all rotating machines. It is unavoidable, and not a problem in itself: Pump designers (and motor designers) design machines to withstand normal vibration limits. These limits vary by pump type, mounting configuration, power requirements, rotative speed and fluid being pumped. The Hydraulic Institute publishes a complete set of standards adopted by ANSI, which cover vibration dynamics, measurement standards, and allowable limits. The standard is ANSI/HI 9.6.4. Details of that standard are not discussed here.

Typically (but not recommended), vibration goes largely ignored until it results in a symptomatic issue. Excessive vibration may lead to excessive noise, equipment damage, and premature fatigue failure. Developments in recent years such as BACnet, SCADA systems, and other building management systems and manufacturer designed and developed systems frequently measure and record vibration in pumps. Developing a benchmark reference, establishing limits, and incorporating vibration measurement as part of any preventative maintenance program will often allow pump service before vibration causes catastrophic failure or other unacceptable results.

Yet vibration itself is not the "root problem": It is caused by something, either internally in the pump or within the system. Those problems are discussed in this paper.

### CAUSES OF VIBRATION

The causes of vibration can be divided into 3 broad categories:

1. Misapplication, design, or manufacture-caused
2. Internally-caused
3. Externally-caused

Often vibration caused through one category will stimulate vibration to such a level that it will lead to difficulty in another.

**Misapplication, Design, or Manufacture-caused**

While this category is by far the most rare, it is often the first one thought of when dealing with a vibrating pump.

Examples of the main causes of vibration which fall into this category include:

- Critical speed issues - This issue is practically non-existent in horizontal pumps running at full speeds: Manufacturers design their products so that the first critical speed is above the highest rotative speed. ("Critical Speed" is the theoretical angular velocity which excites the natural frequency of the rotating equipment. As the speed of rotation approaches the natural frequency, vibration and resonance occur.) In vertical pumps such as vertical turbines with a variety of lengths and heads, critical speeds should be considered prior to manufacture. In horizontal pumps, critical speed will typically result from over-speeding, lack of piping support, or on multi-pump packages where it was not considered. (In the lack of piping support, the piping becomes "part of the pump" in essence, and the critical speed of the system is different than the critical speed of the system. This is akin to the external issues discussed as follows. There are two ways to correct critical speed issues and reducing the vibration to acceptable levels:

  1. Change the natural frequency of the pump. This should be done in consultation with, or assistance from, the pump manufacturer. Common approaches.

  2. Change the rotative speed (useful on VFD

systems). “Lock out”, or accelerate through the critical speed to prevent the machine from operating there.

- Severe cavitation - When cavitation is severe enough (whether NPSH caused or entrained air caused) the energy of the implosion may cause the entire unit to vibrate excessively. Of course, as the cavitation continues, the material of the impeller will erode and vibration will worsen. Proper selection of pumps will avoid this, but of course it may occur as a system ages and piping changes. NPSH will need to be increased or entrained air evacuated in existing systems.
- Corrosion and erosion - While these issues may easily be deemed “internal issues,” they really have their roots in improper selection of material for the pumpage. Damage from corrosion or erosion may damage impellers or rings, leading to a machine which vibrates beyond acceptable limits. Correcting the problem may require analysis of the pumpage. Even in the case of severe erosion from sand and grit, steps may be taken to change materials to eliminate the problem or extend the MTBF.
- Imbalance of the impeller - Impellers should be trimmed and dynamically balanced to the proper diameter at the maximum operating speed in accordance with ISO standard 1940/1, grade 6.3, which allows 0.0014 ounce inches of unbalance per ounce of impeller weight at 1800 rpm (.0007 oz. in./oz. at 3600 rpm). Initial failure to balance the impeller to these standards or failure to re-balance if an impeller is trimmed on an existing pump may well cause vibration outside of acceptable areas. This is important on small machines as well as large, since the standard has been established taking into account the total mass of the machine and the impeller’s impact on vibration. The only remedy is removal of the impeller and re-balance.
- Imbalance of motor rotating element - This is a rare manufacturing flaw. Motor balance testing requirements are established by NEMA in standard MG-1, 2007, Section 1, part 7. Typically issues identified as motor rotor imbalance (by disconnecting the motor and running it by itself) are, in fact, either bent shaft or bearing failure issues, and are discussed elsewhere in this paper. Imbalance of motor rotating parts will virtually always be apparent upon (or soon after) startup. The motor manufacturer should be consulted if warranty is required, or a reputable motor service shop, such as one that is associated with the Electrical Apparatus Service Organization (EASA).

  (http://www.easa.com)
- Soft foot - This vibration causing issue, a relatively frequent one, results when the mounting feet (typically on the motor, but also on pumps without a “one-piece” foot) are not in the same plane. As the foot is tightened down, the frame twists, and vibration results. This also can, and does, occur on cast motors, and may be difficult to initially identify, since the resonance is transmitted throughout the machine, and often the piping. Soft foot usually shows up on startup, or after maintenance. Because of its frequency, unless other “vibration-causing” issues can be easily identified, checking for soft foot is recommended early on in the troubleshooting procedure. One approach uses dial indication to check mounting. Another frequently used approach, is simply to loosen hold down bolting - one at a time - slightly and see if the vibration is reduced or eliminated. If found and loosening was excessive, shimming and re-alignment may correct it. If “left loose,” the culprit bolt(s) should be clearly marked so that it is not inadvertently tightened in the future.
- Coupling out of balance - This is not to be confused with misalignment, in rare cases couplings themselves can be out of balance. This virtually never appears at four-pole speeds and only very infrequently at two-pole speeds. It, rightly, should be investigated when all other causes of vibration have been eliminated. While re-balancing a coupling is possible, complete replacement is often more cost effective.

- Mechanical tolerances - Mechanical tolerances may cause vibration in the machine, even if the individual component tolerances are within the manufacturer's specifications. Simply put, the more pieces that are put together to assemble the pump, the greater the risk (all else being equal) that tolerances will "stack up" to yield a vibrating machine. Individual components, when checked, may be within specification (typically to ASME/ANSI Y14.5). This is further complicated by the fact that the machined parts that may be the problem are used to locate and determine other possible issues. A full check of trueness and plumbness will be difficult to measure accurately in the field but may be the only way to determine this.

  On the other hand, mechanical tolerance-caused vibration may be simple to diagnose if the tolerances directly involve rotating pieces. Parts machined "out of round" or "out of square" may cause binding or grinding of one piece into the other. See below in the "Externally-Caused" section on how to differentiate this from pipe alignment issues.

- Mechanical looseness - For discussion sake, mechanical looseness here refers simply to those cases where nuts and bolts are not properly tightened. Individual cap screws may not have been tightened on assembly, or may have loosened during transport and installation. All external cap screws should be loosened during transport and installation. All external cap screws should be tightened per the manufacturer's recommendations upon assembly and periodically thereafter. (Annually is recommended for most machines.)

**Internally-Caused**

For purposes of this discussion, "internally-caused" refers to within the machine, whether inside the pump or outside the pump. These causes include:

- Misalignment of the pump and motor - This is arguably, the most common cause of vibration in pumps. (See Externally-Caused issues for the contender.) It should be noted, alignment to the pump manufacturer's recommendations (NOT to the coupling manufacturer's limitations) is critical. (Couplings can generally tolerate greater misalignment than can the pumps or motors, but the loads will be transmitted to the pump and motor.)
- Incorrect rotation - While pumps will pump when rotating in the wrong direction, flow and head will be reduced and vibration due to fluid dynamics may result. Rotation should be checked and corrected. (Change any two leads on a three-phase motor, and check the nameplate on the motor for lead correction on one-phase motors, after ascertaining that the pump can run in the desired rotation.)
- Bent shaft - A bent shaft may be caused by a number of field related issues and will result in vibration. Typically, it will impart unequal loads to the bearings and seal and cause premature wear there, even if the level is not sufficient to be detected under normal observatory practices. Of course, checking the shaft for trueness or "run-out" is relatively simple on foot-mounted framed pumps, since the frame forms a platform for the check. Examination of all failed components will usually indicate the cause of failure, both in the seal and bearings.
- Bearing wear / failure - Lack of lubrication or improper lubrication may hasten bearing wear and cause vibration, as discussed elsewhere. Yet even under "perfect" conditions, bearings will wear and fail due to fatigue. Examination of the bearings, and the wear paths and "spalling" within the races will help determine whether or not extraneous forces hastened the wear and helped cause the vibration.
- Clogging - Clogged pumps may not always vibrate excessively, but certainly usually do. If impeller parts become clogged, either fully or in part, they will contain less fluid and may cause vibration. Before a pump is disassembled for clogging, it is advisable to check the motor's current draw. A clogged impeller will draw lower than expected amperage unless the clog causes enough imbalance (and vibration) that there is a rub between the impeller and the

case. (In that case, the vibration would most likely be accompanied by rubbing or grinding noises and an increase in amp draw.)

**External-Caused Issues**

Experience has shown that externally-caused issues cause the majority of vibration problems.

- Pipe strain (misalignment between the pump and the piping) - Pipe strain is arguably (together with pump to motor misalignment) the number one cause, and should be of primary focus in the investigation of vibration issues. Important to consider is adjustment of the pipe supports after water has been introduced. The weight of the water may be considerable, and pipes which seemed properly supported when empty are found to need adjustment when full. The weight of the water may cause enough strain to result in vibration, but also in binding and misalignment or catastrophic failure.
- Poor foundation or anchoring - If the pump's foundation is not flat or the baseplate not properly secured or grouted, vibration may and will likely result, as would be symptomatic of "soft foot." While this may be obvious immediately upon startup, it also may worsen as time passes and the system "settles in." Adjustments to baseplate and shims may correct this, assuming the defect is not too large. Not incidentally, this problem is frequent on close coupled pumps after repairs are made. If a "sub-base" of either cast iron (preferred) or steel is not used, the motor is affixed directly to the floor, usually using pieces of all thread buried in the concrete, with nuts atop it to hold the pump down. Since "back pullout" is not possible with this configuration, the all thread is usually cut to allow pump rotating element and motor removal. The all thread is seldom replaced, and the pump not attached to the floor at all. Vibration and premature failure will result.
- System resonance - Since every system has a number of resonant frequencies, it is possible that "acceptable" vibration within the pump will cause vibration at the system frequency, amplifying the resonant frequency and thereby increasing the vibration within the pump. This may cause component failure. Akin to critical speed issues, adjustment of the piping may be required to remedy this.

## CONCLUSION

Excessive vibration is easily noted and causes much difficulty. It is important to determine the root cause of vibration, so that it can be properly corrected. Since the majority of vibration-causing problems are external or alignment issues, those should be of primary focus of investigation to assure long life and lower life cycle costs.

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Being responsible is our foundation
Thinking ahead makes it possible
Innovation is the essence


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