Measuring displacement using accelerometers

By Renard Klubnik, Applications Engineer

Displacement is the most easily understood vibration parameter, yet is the least commonly utilized in vibration analysis.

> Plant personnel have long expressed a desire to know the amount of 'mils' at which a machine is operating, because 'mils' is a readily understood parameter. One can easily feel displacement by placing a hand on a piece of machinery. Some of the earliest vibration 'sensors' included a pencil mounted on a machine that scribed a line on a card. The 'peak-to-peak' level of vibration could then be measured with a scale. Highly sophisticated vibration monitoring instrumentation exists today, but displacement remains one of the most sought after vibration parameters because it is easy to understand.

There is a common misconception that measuring displacement using an accelerometer is not possible or can lead to erroneous information. In reality, accelerometers have long been used to measure displacement. However, it is important to understand that displacement measured with an accelerometer is not the same displacement measured with shaft riders or eddy current style vibration transducers.

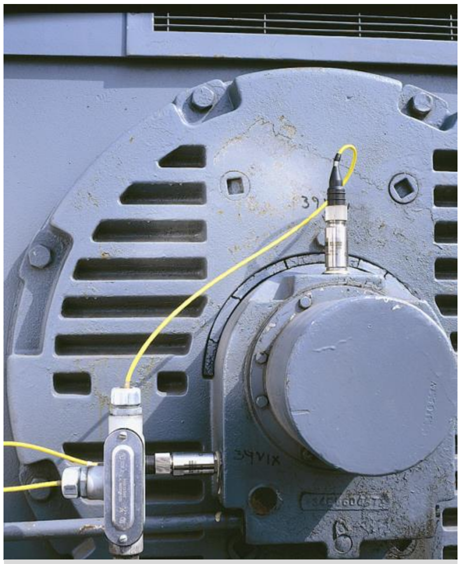
Eddy current probes are precisely thru-hole mounted into a mechanical casing and measure two very important shaft parameters. First, eddy current probes indicate the location of the shaft relative to the casing. This is very important in sleeve bearing applications because it tells the operator where the centerline of the shaft is relative to the casing. Second, eddy current displacement measurements indicate the amount of 1x rotational vibration. From this measurement, it can be determined if the shaft vibration is within acceptable limits. If an operator looks at the vibrational spectral content measured with a displacement probe, it is possible to see higher order harmonics of the shaft. However, these levels are typically very small in amplitude due to the natural inclination of rotating machinery to dampen and attenuate vibration displacement levels at higher frequencies. Other uses of eddy current probes are to monitor shaft eccentricity or, in the case of probes positioned in the axial direction, to monitor case thermal expansion.

While all of these measurements are useful, they are not the same as a casing vibration measurement made with an accelerometer, then doubly integrated electronically to determine the level of machine displacement. While eddy current probes are widely used in sleeve bearing applications, a great majority of field machinery employ roller element bearings. Usually it is neither possible nor practical to mount an eddy current probe on this type of machine. Since the shaft is held tightly in place by a roller element bearing, an accelerometer mounted on the case will detect the force exerted on the bearing by the rotating mass.

The benefits of using accelerometers to sense machine vibrations through casing measurements are well known and have been in general practice for generations of equipment. Typically, accelerometers internally generate an output voltage proportional to g's, and 100mV/g is the common reference value. After the accelerometer output signal is received by the measurement instrumentation, the acceleration signal is converted to either velocity or displacement. Depending on the preferred measurement parameter chosen by the plant reliability engineer, the velocity and displacement characteristics are trended against time to indicate when the machine condition has changed enough to warrant special attention or preventative maintenance.

While this method is effective, it requires a high degree of instrumentation to accomplish the desired goal of preventing machine failure. The measurement instrumentation involved is usually a spectrum analyzer which collects, conditions, manipulates, and displays the data. The raw accelerometer data is often transferred to a software database package that offers significant additional analytical capabilities and record keeping. There is considerable expense in the measurement instrument, training personnel in its proper use and interpretation of the data, and ongoing software updates. This approach has been successfully implemented in thousands of plants over the last several decades and has saved industry countless dollars in unscheduled downtime and costly repairs on large, critical machinery.

However, there remains a large number of unmonitored balance of plant machinery that could benefit from vibration analysis. The expense of utilizing highly trained staff to collect hundreds or thousands of data points makes it impractical, especially when one considers the increased demand on personnel to “accomplish more with less.”



4-20 mA sensors provide cost-effective continuous monitoring of balance of plant equipment.

In recent years, there has been increasing interest in loop powered vibration sensors, which are powered from 24 volt supplies and output a 4-20 mA signal. The advantages of using 4-20 mA vibration sensors are simplicity and cost-effective continuous monitoring. They take the same accelerometer-based vibration signal discussed above, internally process that signal using one of several detection schemes (rms, peak, peak-to-peak, or true peak), and convert it into a 4-20 mA signal that is proportional to either acceleration or velocity. This signal is then routed to a much more common piece of process equipment such as a PLC or plantwide DCS system. Now, instead of spending tens of thousands of dollars on sophisticated instrumentation, a plant can invest about $300 per data point and get continuous real time data on any piece of equipment. Plants are now able to monitor many more pieces of equipment cost effectively. Considering the plant investment in capital equipment, this is a very small price to pay for continuous operating information on a critical pump or fan stationed remotely in the plant. Even the higher priced analytical system does not offer 24/7 protection and usually requires human interpretation.

While all of the loop powered vibration sensors up to this time based the 4-20 mA output signal on acceleration or velocity, measuring displacement with a 4-20 mA sensor is now an option. With no cabling and no instrumentation before it is converted to displacement, the cleanest signal is possible (where cleanest is defined as the least amount of electrical, thermal and cable noise before conversion). As previously mentioned, in traditional walk-around vibration systems, it is standard practice to convert the accelerometer signal to displacement after the signal reaches the measurement instrumentation. The result often seen in this data has been characterized as ‘ski slope’, where low frequency signals are lost in the integration process.

With an accelerometer mounted on the machinery, the processing is performed right at the point of data collection. It is possible to control the entire measurement and integration process to a much greater degree than was previously possible. The acceleration signal coming from the sensing crystal is first conditioned, that is, made readable by subsequent measurement amplifiers. Once amplified to an acceptable level, the signal is passed through a double integrator, which is similar in design to a low pass filter. This AC signal, representative of the machine displacement, is fed into the averaging circuit, converted to the required DC value, and passed out of the sensor as a 4-20 mA signal. Now, data screens for process control machinery can be calibrated in mils displacement in the same manner that vibration velocity signals have been recorded with previous generation sensors.

Through simplicity and the low cost of continuous monitoring, direct reading, accelerometer-based 4-20 mA displacement sensors expand the opportunity to use vibration monitoring within a plant. Fans, for example, offer a significant benefit from this technological improvement. When an accelerometer is sensitive to velocity, the overall vibration level can be dominated by blade pass frequency.

By utilizing a sensor based on displacement, the high blade pass frequency (relative to 1x vibration) is attenuated in the signal resulting in a monitoring system that is focused on the rotational (balance) component of the system. Figure 1 shows the vibration readings of a fan in terms of velocity and in terms of displacement.

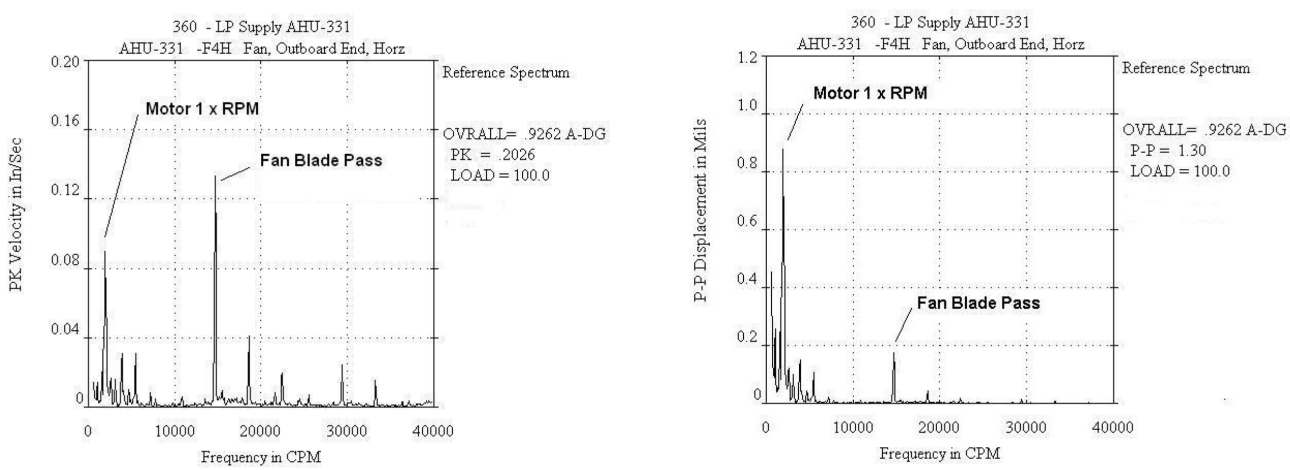


Figure 1: Fan vibration readings in terms of velocity and in terms of displacement.

Loop powered 4-20 mA displacement sensors can also improve pump monitoring, because the pump vane pass frequency can dominate a spectrum. Velocity sensors may be blind to changes in rotational speed vibration and therefore are not the ideal measurement parameter. 4-20 mA sensors mounted on fan pillow blocks or pump housings can output directly to process control points, providing operators with never before seen information on their machines. Figure 2 shows the vibration readings of a pump in terms of velocity and in terms of displacement.

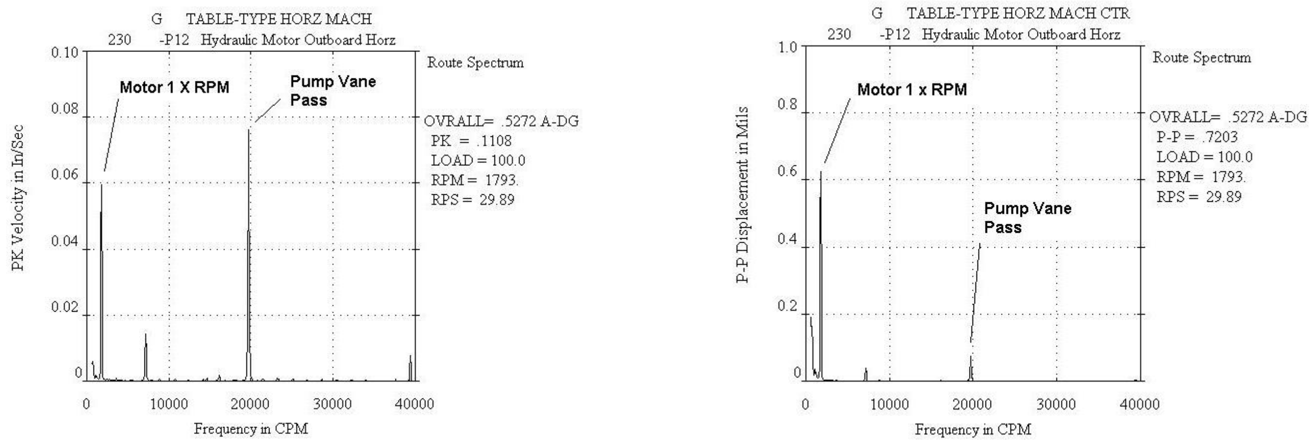


Figure 2: Pump vibration readings in terms of velocity and in terms of displacement.

While measuring displacement is useful in many instances, most reliability engineers and maintenance managers realize that a single measurement focused on a single parameter (acceleration, velocity or displacement) is only a small part of a comprehensive predictive maintenance program. The choice of available sensors for measuring vibration is constantly changing. Advances in technology enable us to increase the measurement range of sensors; the bandwidth, both low end and high; and ability to resolve low level signals in the presence of high signals like imbalance. The recent acceptance of loop powered 4-20 mA vibration sensors continues to expand the capability of predictive maintenance and real-time monitoring. Displacement based accelerometers are the latest addition to the arsenal of vibration measurement tools and provide an easy to understand measurement with the capability to unmask hidden problems.