The ABC's of Machinery Vibration Transducers

Transducer Types, Construction and Characteristics

There are three basic types of transducers commonly used for machinery vibration applications. They may be described as follows.

Accelerometer

Construction usually consists of a piezoelectric crystal with a mass/spring preload and (often) internal electrical circuitry for signal pre-amplification (in which case, external electrical power is required). A voltage is generated by changes in the force upon the piezoelectric crystal and is proportional to acceleration (Force = Mass × Acceleration). There is usually insignificant internal mechanical motion, thus accelerometers are virtually immune to mechanical wear. However, excessive mechanical shock (for example, gross impact damage, dropping upon a hard surface, etc.) can self-generate voltages sufficient to destroy internal electronic components (if internal preamp circuitry exists) or fracture the piezoelectric crystal.

Accelerometers generally have the widest frequency range and certainly the highest. However, vibratory response and electrical signal levels are limited at lower frequencies. Sensitivities are usually tens or hundreds of mV/g, peak (1 g = 9,8 m/sec^2 = 386.1 in/sec^2). Charge-type accelerometers (as opposed to voltage type) have sensitivities measured in pico-coulombs (pc) per g, peak; they are often used for higher temperature applications.

Velocity transducers

Construction consists of a movable, fine wire coil in a magnetic field that generates a voltage by the Hall Effect principal of physics. The voltage generated is proportional to the velocity of the coil motion. No external electrical power is required and signal levels are usually high enough to be used without pre-amplification. Coil mounting and motion is accomplished by precision mechanical devices often similar to precision electrical meter movements. Therefore, velocity transducers may be more prone to wear and mechanical damage than the other (two) types of vibration transducers.

Velocity transducer vibratory response (usually a lower frequency range than accelerometers) and signal levels cover a range generally useful in machinery applications. Sensitivities are usually many (hundreds) mV/in/s (ips.), peak. As with accelerometers, velocity transducers must be securely mounted in contact with the surface being sensed.

Fig. 1. SKF vibration sensors.

Eddy probes

Fig. 2. SKF eddy current probes.

(Non-contact, inductive). Construction is usually a small, flat "pancake" fine wire coil covered by a thin, non-conductive, protective sheath. A high frequency energizing current creates an electromagnetic field around the coil areas. Within this field, position and changes in displacement (vibration) of electrical conductors (metals) may be determined with great precision. An oscillator/demodulator and energizing power source (usually referred to as a "driver") is required, as well as precisely matched electrical interconnect cables between the probe and driver. Changes in position/displacement may be sensed with various non-conductive fluid media (e.g., air, gas, liquid) between the probe and the sensed metallic surface. The eddy probe is the only commonly used non-contact vibration transducer. Surface condition (finish, alloy, temper, etc.), non-symmetry (eccentricity, flat spots, etc.) and other characteristics of the metal surface being sensed can influence the displacement indication of the eddy probe. Wear is not a consideration; however, the coil sheath/covering materials are, by necessity, very thin (often only 0,25 to 0,64 mm *(0.010 to 0.025 in.)* thick) and thus may be damaged by accidental impact.

Eddy probes have a wide frequency range and the lowest of the three transducer types. Sensitivities are usually on the order of 100 to 200 mV/mil (1 mil = 0.001 in.) peak-to-peak displacement. The gap distance between the probe coil and sensed surface is usually limited to about 2,5 to 5,0 mm *(0.1 to 0.2 in.)* or less. Eddy probes are also often used to provide shaft tachometer (speed) signals by sensing a shaft surface mark, hole or projection.

Machinery and mounting considerations

Machine speed

The primary parameter that influences the choice of transducers is machine shaft rotating speed. Where frequency (Hertz, Hz, in cycles per second) is equal to r/min ÷ 60, the shaft speed determines the fundamental vibration frequency of interest. Generally, it is desirable that the transducer yield usable information over a range from 0,4 to 1,0 times running speed frequency to several times running speed frequency (3X to 6X). A "healthy", correctly installed machine will usually generate most vibration at running speed frequency. Reasons for interest in multiples of running speed frequency are discussed as follows.

Machinery types and elements

Also of great importance in selecting vibration transducers is the type of machinery and associated hardware. Machinery with blade or vane elements (pumps, fans, compressors, turbines, etc.) may generate vibration signals of interest at frequencies equal to the number of blades/vanes times the running speed frequency; accelerometers are often required in these instances. The amplitude and utility of these signals are strongly influenced by the blade/vane versus rotor/shaft versus housing/cover mass relationships. Thus, fans and pumps with relatively massive blade/vane elements with respect to their shaft/rotor masses may yield much useful data. But, turbine and compressor blades with relatively small mass with respect to their large rotor/shaft mass often yield vibration signals, which may be less significant and can be more difficult to sense and measure (however, these signals are very useful in vibration spectrum analysis as opposed to monitoring).

The most useful and practical source of vibration information from machinery is often from bearing areas. Sleeve and journal bearings are excellent sources of machinery vibration signals in that there are fewer mechanical elements between the machine shaft and vibration transducer (e.g., oil film, babbit, tilt-pads, bearing cap/housing, etc.). Eddy probes are usually a preferred choice with sleeve/journal bearings. Anti-friction (ball and roller) bearings generate useful vibration signals at running speed and much higher frequencies associated with ball-pass frequencies (number of ball/roller elements times the running speed frequency), and inner/outer race and cage related frequencies. These signals indicate anti-friction bearing condition in addition to other vibration signals transmitted from other machine related sources. Accelerometers (and sometimes velocity transducers) are the usual choice with anti-friction bearings due to frequency response and difficulty (or impossibility) in mounting eddy probes.

The mass and stiffness of all major elements of the machinery installation must also be considered. Foundations, frames, piping, shaft, rotor, case, coupling, bearing, bearing housing, etc., all contribute links in the transmission chain for vibration signals. In addition to resonance and critical speeds, these elements may alter (amplify or attenuate) vibration signals of interest. Generally speaking, a lightweight and flexible element may generate significant signals and alter vibration signals from other machinery elements. Heavier, stiffer elements may act as more accurate conductors or transmitters of vibration signals.

Transducer mounting

The transducer mounting method and location can ruin an otherwise valid transducer selection. All vibration transducers should be located to minimize the influence of spurious or unwanted vibration signals and sense vibration signals of interest as directly (with a minimum of intermediate hardware) as possible. Frame, foundation and piping (generated and resonant) signals can obscure desired signals from the machinery itself. Recommended mounting locations are on bearing caps and gearbox cases and machine cases, if the mass and stiffness criteria above are met. “Mapping” and selection of particular mounting locations is best accomplished utilizing some type of portable vibrations indicating instrument.

The transducer should be mounted as securely as practical with a minimum of extraneous mounting hardware. Accelerometers and velocity transducers should be mounted on a flat, smooth, machined metal surface. Eddy probes should have their threaded cases securely fastened to a solid, rugged surface. Exercise caution when utilizing mounting pads, brackets and adapters so as to minimize extraneous vibration in the mounting hardware itself and/or possible damping. The orientation of the transducer should be in a plane that correlates with motion of the machinery itself, (for example, usually radial and/or axial to the shaft axis).

Frequency, signal and vibratory response

Frequency response

Vibration transducers have a manufacturer's rating for the frequency range over which it is capable of providing accurate data. These specifications should be carefully reviewed, particularly as to the accuracy tolerance at the extremes of the frequency response range. This is often expressed as “plus-or-minus” some percentage or decibel (dB) figure. Thus, a 10 Hz to 10 kHz, ±3 dB transducer may actually have less frequency response range than a 15 Hz to 8 kHz, ±0.5% transducer. As stated before, the transducers response should be relatively linear (flat) from about half to a few times the machinery running speed frequency (the transducer should also not be resonant in this range).

Signal levels

Vibration transducers are also rated as to sensitivity or output. This is usually expressed as transducer output per vibration unit (mV/mil, mV/ips, mV/g). When vibration levels of interest and corresponding transducer voltage output levels result in signals under a few millivolts (1 to 5 mV.), the electrical noise and grounding of the entire electrical circuit should be carefully reviewed. It is often difficult to reduce installation electrical noise level below a few millivolts. Transducer sensitivities must also be compatible with vibration monitoring instrument sensitivity. The following example may help illustrate this:

Table 1

Running	Machine speed	Speed Frequency	Vibration amplitude Mils	ips	g
1.	600 r/min	10 Hz	3	0.1	0.02
2.	3 600 r/min	60 Hz	2	0.4	0.40
3.	12 000 r/min	200 Hz	1	0.6	2.00

Vibratory response

For lack of a better term, we are distinguishing frequency response from "real-world" machinery vibration via the term vibratory response. While vibration transducers often have a wider frequency response range, this can be misleading in terms of their value for sensing machinery vibration.

Notice we have elected to reduce the vibration displacement with increasing machine speed, as this is what often happens in real life (high speed machinery usually has tighter fit tolerances). Also note that at low speed, we have high displacement, limited velocity and negligible acceleration. However, at high speed the reverse is true – you get more g's and less mils at high speed (and conversely, more mils and less g's at slow speed).

This is why displacement probes may be the only reasonable choice at very slow machine speeds and accelerometer may be preferred at very high machine speeds. This is also the reason velocity transducers have attained popularity as a general purpose transducer.

The previous figures become even more important when you relate transducer sensitivities to expected signal levels and system electrical noise factors mentioned above. An accelerometer with a sensitivity of 100 mV/g will only have 2 mV output for 3.0 mil displacement at 600 r/min (10 Hz). This is often an impractical signal level to consider for machinery vibration monitoring applications (even though it may be within the specified frequency response range for that accelerometer). Thus, accelerometers may be impractical for slower machines (lower frequencies) and eddy probes incorrect for some very high speed machinery (higher frequencies), even though the frequency range of interest is apparently compatible with the transducer's specification for frequency response.

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PUB CM1007 EN · February 2012