APPENDIX 3

PROPER MODE OF MEASUREMENT

In using a meter, monitor or analyzer to determine a problem or condition, what is the best mode (units of measure) of measurement? This chapter discusses the pros and cons of using the displacement, velocity, or acceleration modes of measurement. DO NOT confuse mode of measurement with the type of transducer used, for as you will see in the chapter on transducers, one type of transducer can be used to measure all three modes of vibration.

DISPLACEMENT

Historically, many users have taken vibration histories in terms of mils displacement, because displacement measurement appears to be the best indicator of the condition of the machine. A closer examination of the problem will prove this to be untrue. A piece of machinery might shake one mil "peak-to-peak" at 1000 rpm and experience no adverse effects from this vibration; in fact, a machine with this level of vibration would be considered by most users to be in very good condition. However, if the same machine were shaking one mil at 10,000 rpm, the machine would indeed be in serious difficulty. It can be seen that if vibration is to be measured in terms of displacement, it will also be necessary to determine the frequency of that displacement in order to understand the severity of the problem. In applying a vibration monitor to a piece of equipment, problems are created if displacement is the characteristic to be measured. A vibration monitor normally monitors only one vibration characteristic, amplitude, and its purpose is that when a certain amplitude level is reached a trip will occur. This trip may simply sound an alarm or it may shut the machine down. If we determine that displacement amplitude is the characteristic to be monitored, it becomes very difficult to set the level at which the monitor should trip. If we consider the vibration levels that were discussed above, it can be seen that we should not set the trip at one mil, since the machine would shut down or trip an alarm any time a one-mil displacement occurred at 1000 rpm. We have already determined that one mil at 1000 is not at all dangerous. On the other hand, it must trip if the vibration reaches one mil at 10,000 rpm, since this magnitude at this frequency would represent a serious vibration.

If it were desired to monitor the vibration at only one specific speed or frequency, displacement could, of course, be used since it would be possible to establish an acceptable vibration limit at a given speed. It is also true that displacement measurement may be more useful at low speeds than other modes of measurement. The reason for this is that at low speeds the limiting factor as far as vibration is concerned is the amount that the machine is physically able to move without a mechanical failure of a supporting member. This is to say that movement of 1/16 of an inch at 100 rpm may not cause any damage to the bearings of a machine, but may very easily crack the feet supporting the machine.

Thus, it can be seen that while displacement is useful at low speeds (generally below 1000 rpm) and at specific frequencies, it is not the best mode of measurement for a machine that would be operating over a variable speed range or a machine where it is desirable to measure vibration over a wide frequency range. It should be noted here that even though a machine may be running at only one speed, it could generate many different frequencies of vibration due to different mechanical problems.

VELOCITY

Velocity measurement is a valuable mode of vibration measurement over a wide speed range for two reasons. In the first place, vibration is a form of energy. Therefore as the level of vibration energy increases, the possibility of damaging effects on the machine increases also. In general, the energy

dissipated in the machine in the form of vibration can be described in terms of velocity of motion. The velocity measurement therefore is a measurement of that vibration characteristic which is most indicative of damage to the machine. The relationship of velocity to energy can be seen in the equation:

$$K.E. = 1 / 2\, mV^2$$

where K.E. is energy, m is mass of the machine, and V is velocity of vibration

The second reason that makes velocity an attractive mode of measurement also deals with the energy concept. Note that frequency is not in the above equation. Therefore, it can be seen that if one inch per second vibration velocity is damaging at 10,000 rpm, it is also damaging at 1000 rpm. This means that we need not be concerned about the speed of the machine we are monitoring, since it is possible to set a vibration limit on the monitor which will be good for a wide range of speeds. It is then only necessary to determine what velocity is damaging to a specific machine.

In general, velocity is the most useful mode of measurement for a wide frequency range of monitoring or for a machine that operates over a variable speed range. It is also the only characteristic which by itself is indicative of machine condition. Both the other modes of vibration measurement (displacement and acceleration) require a frequency consideration.

ACCELERATION

An acceleration measurement is a measurement of the force being applied to a machine. This is a good method of determining how much damage is being done, except that frequency is a consideration. At low speeds accelerations may produce large deflections or displacements in the machine. The same acceleration at high speed may cause no damage at all. We are, therefore, again faced with the problem of being unable to set a limit level which would be useful over anything but a narrow frequency range. On the other hand, acceleration is a useful means of measurement on machinery operating above 10,000 rpm. (Some authorities place this level at approximately 6,000 rpm). At these speeds even small accelerations cause vibration which would be above the acceptable level of the machinery.

Work has been done to try to establish safe acceleration levels for machinery. As a guideline 2g's has been established as a fairly good limit for allowable accelerations in high speed rotating machinery. But, at best, this can only be applied as an average. Individual machines will differ considerably in their tolerance and vibration forces. Acceleration is also a good choice if sharp transient response is needed such as detections of detonations in a natural gas engine. Acceleration is a poor choice at low speeds since the machine would literally be shaking itself to pieces before a reasonable acceleration trip level is reached. An example of this would be a monitor set for trip at 1 g. If the machine being monitored were operating at 300 rpm it would require almost .8 of an inch (800 mils) movement before 1 g trip level could be reached.

It should also be noted that on some high speed machines extremely high g levels occur with no apparent damage to the machine. Examples of this are harmonic signals in jet engines representing burner can passages that appear at several thousand cycles per second. If these accelerations were allowed to trip an acceleration monitor, shutdowns could result unnecessarily. Values as high as 40 g's have been observed in jet engine cases with no indication of failure. There are two solutions to this problem. One is a filter to limit the high frequency response to the monitor. A second is to set the g level trip higher to accommodate the true g levels.

It can be seen by the previous discussions that it is indeed difficult to try to set definite rules for modes of measurement. In general, it can be said that displacement is a good mode of measurement for low speed operations. Velocity is an attractive measurement since it has the ability to provide at least some degree of protection on an energy basis for all frequencies of machine operation. Acceleration measurement is a useful mode for high speed operation (above 10,000 rpm) for detection of sharp transients, or for detection of faulty anti-friction bearings or gears. If there is an opportunity for only one mode of signal response between displacement (mils), velocity (inches per second), or acceleration (g) for a machinery shutdown or warning device, it appears that velocity is the best compromise, and certainly the simplest choice.

When measurement of the shaft relative to its sleeve (or similar) bearing is desired, or when relative motion between other rotating and non-rotating parts is desired, there is no substitute for the non-contacting probe for the measurement. It is the only transducer that does not contact the vibrating surface.