Pseudo Electrical Faults

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Electrical faults in induction motors can generate vibration energy at two times the line frequency (typically 7200 CPM). In some cases, however, such vibration energy is due more to a system resonance than significant electrical faults.

Electrical faults do occur in motors. However, personal experience has identified vibration characteristics that are classically considered indicative of such faults far more often than are electrical faults themselves found to exist. In particular, two times the line frequency (7200 RPM or 120 Hz) energy is not uncommon in a frequency spectra found in vibration data obtained from a three-phase induction motor.

Such data are considered indicative of electrical faults. The reason for this is that as the armature of an electric motor rotates, it passes the electro magnets in the stator. There are three electro magnets in each pole, one for each phase. The electric current in each phase oscillates sinusoidally at line frequency. This results in the magnetic field rotating. This is somewhat difficult to conceptualize, because nothing physical in the stator rotates, only the electric field.

The armature, which is basically an electro magnet, rotates to keep aligned with the rotating magnetic field. The physical speed of the armature will always be slightly slower than that of the rotating magnetic field. Without going into the reason for this too deeply, this difference, generally referred to as the *slip speed*, is necessary to induce current into the rotor cage, making the armature an electro magnet.

The rotating speed of the magnetic field is generally referred to as the *synchronous speed*. Synchronous speed (SYN SP) can be determined with the following equation:

$$\text{SYN SP} = \frac{\text{Line frequency}}{\text{Number of setsofpoles}} \tag{1}$$

Line frequency is most often 3600 CPM (60 HZ) in North America. One set of poles is one north and one south. As such, the synchronous speed of a:

- Two-pole motor is 3600 CPM
- Four-pole motor is 1800 CPM
- Six-pole motor is 1200 CPM

The necessity to have a slip speed is why the rotating speed of a two-pole motor might be 3580 CPM and not 3600 CPM. This subtle difference is potentially very valuable in determining the type of fault that may be causing a vibration problem. If the frequency of the fugitive vibration is 3580 CPM or a multiple, the fault is most likely mechanically induced. But if it is 3600 CPM or a multiple, it is most likely electrically induced.

Even though, for routine monitoring, it is generally not practical to program an analyzer so that the difference between synchronous and rotating speed can be resolved, most analyzers today contain mathematical algorithms that can determine the numerical value of each peak in a frequency spectrum. If the numerical value of a particular peak is between the synchronous and rotating speeds, it is likely that there are both electrical and mechanical contributions.

Getting back to the 2× line frequency vibration, if there is a fault in one of the phases, the current in that phase and thus the strength of the magnetic field will be affected. The fault could be poor insulation, allowing ground leakage or excessive impedance in that phase. In any case, the strength of the magnets supplied by current from that phase will be less than that supplied from the other phases. This will result in a forcing function the frequency f of which can be calculated by the formula:

$$f = (\text{Sync SP})\ (\text{Number of poles}) \tag{2}$$

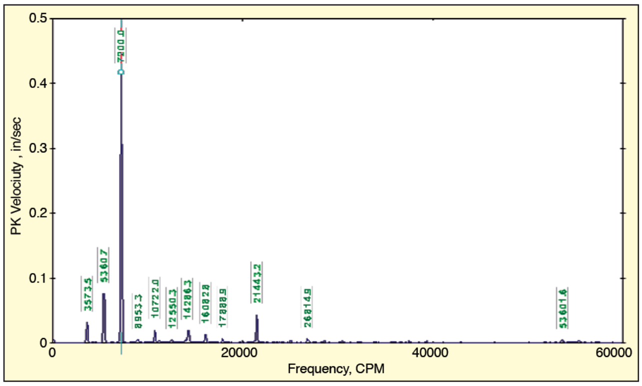

Figure 1. Frequency spectra obtained for drive motor of large vacuum pump; note high level of 2X line frequency vibration (~0.4 IPS).

This value will always be equal 2× line frequency. In a two-pole motor, two pulses will be created per revolution of the field (not the armature):

$$f = (3600)(2) = 7200 \text{ CPM}$$

In a four pole motor:

$$f = (1800)(4) = 7200 \text{ CPM}$$

Another important item to appreciate is that in motors with more than two poles, the fault may be in only one point on one coil, but because the same current continues on to successive coils, the strength of the current in those coils will also be diminished. So a pulse will be generated each time a pole is energized.

In the preceding scenario, 2× line frequency vibration energy can be indicative of electrical faults, but this is only valid if there is a relative difference between the current in the different phases. Another term for such a condition is a phase unbalance. In a situation in which there is a general and symmetrical degradation in the condition of the windings (all windings are equally bad), there may be little or no phase unbalance, and no significant 2× line frequency vibration energy, but the motor could still have significant electrical faults.

As noted earlier, 2× line frequency vibration energy will almost certainly be electrically induced. However, if the strength of this energy is not too strong and it does not change with time, it is not generally indicative of a significant problem. This is particularly true if there are multiple motors of the same design and all have similar vibration characteristics.

However, if the magnitude of the 2× line frequency energy increases with time, it is likely that an electrical fault is progressing and should be addressed.

Discussion and Case History

This discussion has been a somewhat long-winded dissertation regarding the relationship between 2× line frequency vibration and electrical faults in motors. However, several cases have been encountered in which a high and even a very high level of 2× line frequency vibration energy has been encountered, but no significant electrical faults were found. Also, in some of these cases there was a large disparity between the amplitude of vibration from one orientation to another. One such case was the drive motor of a large vacuum pump. In the horizontal orientation, a high level of vibration was generally found (see Figure 1). However, in the vertical orientation, a much lower level was often found (Figure 2). This motor has been checked, but no significant electrical faults were found.

Motors with such a large disparity from one orientation to another have been encountered on several occasions. Any time a machine is encountered in which there is a large disparity between the levels of vibration from one orientation to another at the same point, whether the frequency is characteristic of an electrical fault or not, a resonant condition should be suspected. However, because

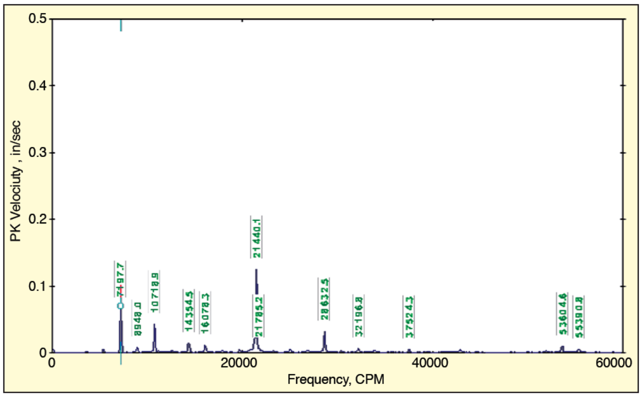

Figure 2. Transfer function showing level of vibration imparted to system per unit of force excitation; note strong peak at 7200 CPM.

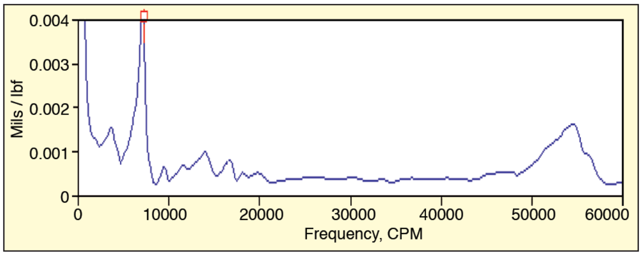

Figure 3. Transfer function showing level of vibration imparted to system per unit force of excitation; note strong peak at 7200 CPM.

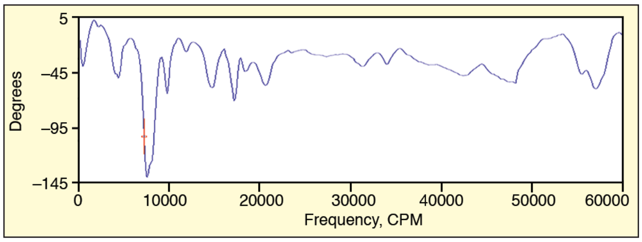

Figure 4. Phase shift versus frequency; although difficult to see frequency scale, large frequency shift occurs at 7200 CPM.

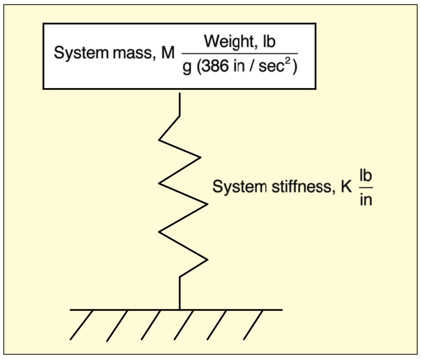

Figure 5. Simple mass spring system consisting of mass supported by spring.

2× line frequency vibration energy is so often associated with electrical faults, the first effort toward corrective action was to check the motor for electrical faults. In this case, no electrical faults were found.

The next effort was to perform a series of resonant frequency impact tests or bump tests. In such a series of tests, a structure is excited with a blow form a calibrated hammer, and the system response is measured with a vibration transducer mounted on the structure of interest. Such a test is employed to determine the natural or resonant frequencies of the structure.

Figure 3 is the transfer function obtained from the bump test. The large peak at 7200 CPM is evidence of the existence of a resonance. Figure 4 is the phase shift versus frequency obtained from the bump test. At a resonance, there will be a large phase shift. This is seen in the plot at a frequency of 7200 CPM. These two plots together provide conclusive evidence that there is a system resonance at approximately 7200 CPM.

To address a resonance problem, it is first necessary to have a basic understanding of how a vibrating system works. Most vibration system can be modeled as shown in Figure 5.

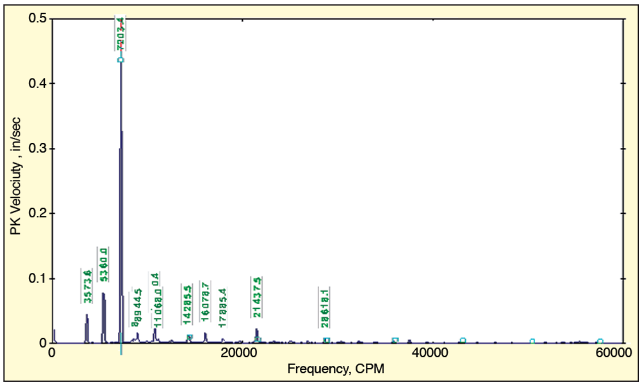

Figure 6. Frequency spectra obtained with all four motor feet fasteners tight; note high level of 2X line frequency vibration energy.

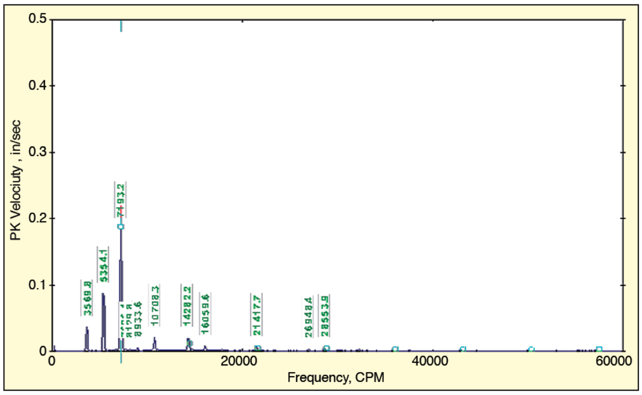

Figure 7. Frequency spectra obtained from same machine immediately after two motor feet fasteners were loosened; note significant drop in level of 2X line frequency vibration energy.

In such a system, the resonant frequency can be determined with the following equation:

$$\omega = \sqrt{\frac{K}{M}} \tag{3}$$

where ω is resonant frequency in radians/second, $2\pi f$ in Hz; K is stiffness, lb/inch of deflection; and M is mass (weight/gravity), lb-sec^2 /inch.

It should be understood that all mechanical systems have resonant or natural frequencies. Resonant frequencies are generally not a problem unless they match a resident forcing function. If this occurs, a high level of vibration will likely occur even if the forcing function is not strong.

So, what can be done about such a condition? From Equation 3, it can be seen that changing either M or K will change the resonant frequency. M is relatively easy to change by just bolting a weight to the system. This will lower the resonant frequency. K or stiffness can sometimes be changed by installing additional fasteners. This will increase the resonant frequency. However, this is often difficult, because there must be a point of attachment on both the system and the substrate.

Another approach that is often effective is to change the configuration of the system restraints. This is a form of changing the value of K. In the case of this motor, this was done by loosening the hold-down bolts on one side of the motor. Applying this approach should proceed with *extreme caution*! In a typical, horizontally mounted motor with four feet, the feet on one side of the shaft axis will be in compression, and those on the other side will be in tension. *Always* loosen the feet that are in compression. Otherwise, the motor might lift. The hold-downs only have to be loosened enough to take the tension off the fasteners. If the machine is to be left in this configuration, the nut can be loosened a mil or so and then double-nutted to keep it from loosening further. This is better than just removing the nuts, because it prevents the system from moving too much should some form of system upset occur.

The results of such a change in the system can be seen in Figures 6 and 7. In Figure 6, a set of vibration data was obtained with the system operating under normal conditions. Then the two fasteners on the compression side of the motor were loosened, and a second set of data was obtained (Figure 7). The level of vibration found with the feet loose was about one-third that found with the feet tight.

Because there is still vibration energy at 2× line frequency, there is likely some level of electrical imbalance. However, if the vibration characteristics do not indicate that the condition is worsening and the level of vibration is within acceptable limits, there is little need to expend what could be significant resources addressing a minor fault that will have little or no affect on machine operation and longevity. In this case, before the feet were loosened, the level of vibration at the 2× line fugitive frequency was approximately 0.43 IPS. This level is high enough that machine service life will likely be significantly reduced. However, the level after the feet were loosened was approximately 0.18, which is low enough that service life will likely not be significantly affected.

Summary and Conclusion

Whenever vibration energy is found at 2× line frequency, the forcing function will be electrical and may indicate a significant electrical fault. Such a motor should always be tested for faults. However, if no significant faults are found, particularly if there is a large disparity between the levels of vibration in different orientations at the same location, the vibration may be due more to a system resonance than electrical shortcomings.

The presence of a resonance can be confirmed with a resonant frequency impact (bump) test. If the presence of a resonance is confirmed and if the level of vibration is high enough that is should be reduced, the most effective approach will be to employ methods to address the resonance. From personnel experience, resonance conditions are actually more common than electrical faults and need to be addressed. S|V

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