Designing Around Vibrations

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When designing new rotating equipment, a new facility with rotating equipment, or installing new rotating equipment in an existing facility, being cognizant of potential vibrations can pay off with lower operating costs. I emphasize rotating equipment because it's often the action of a shaft, fan, wheel, pump, or other spinning element that induces vibration. That act of spinning—or rather, the spinning action of the element—is where imbalance, misalignment, offset loading, and other imperfections become unwanted vibrations. To prevent those imperfections from becoming maintenance headaches, the designer should be aware of a few critical concepts about rotating equipment:

Natural Frequencies and Harmonics

I'm about to make an audacious statement: All things vibrate at a certain frequency. Even a blade of grass, held in the gas between your thumbs, will vibrate if blown on with the right velocity of air. This is a Natural Frequency, the number of oscillations in a second that something will inherently vibrate at. It's crucial to know the natural frequencies—not only of the designed system but also what the system is mounted to—to not accidentally excite a response in something unrelated to the installation. For beams, plates, and other structures, derivative equations from the stresses and strains can be used to find the natural frequencies. For more complex assemblies, Finite Element Analysis programs commonly have Eigenvalue functions for the fundamental frequencies.

Harmonics are when some forcing function—say, an out-of-balance fan—excites a natural frequency of something else. The lowest natural frequency, known as the first harmonic, is the easiest to force into response; it takes the lowest energy to excite, and the response has the highest magnitude. Note, though, the frequency of the forcing function does not have to be at the first harmonic; it could be a multiple of the first harmonic.

Bearing Selection

Rotating equipment, to last for any amount of time, needs to be supported on bearings. The types of bearings are as varied as the applications—hydrodynamic bearings, sleeve bearings, rotating element ('anti-friction') bearings, and even magnetic bearings. Each has its advantages and disadvantages, which are beyond the scope of this article. The choice of bearing and bearing mount is another crucial aspect of designing around vibrations. Ideally, any two sets of bearings should be precisely aligned. Inside a machine, it can be done fairly simply—make sure the case or body is rigid and the bearing mounts are concentric.

Once the bearing mounts are no longer integral to the housing, then alignment is more problematic. A plain bearing in a misaligned mount is subject to a number of failure modes that result in vibrations. Consider self-aligning or spherical bearings when using pillow blocks in equipment.

Mounting

When mounting equipment, it can be critical to ensure the mount is suitable for the equipment and for the foundation. Rubber pads, blocks, and cones have been used to dampen higher frequencies from equipment into a foundation. For lower frequencies, consider springs or wire coils to dampen the greater amplitude generated by low frequencies. For many applications, such as large engines and forming machinery, damping vibrations is not possible because of the rigid support this equipment needs. It becomes part of the design to make a very rigid foundation with a high first harmonic and use a bedding compound to ensure full contact between the machinery and the foundation.

Lastly, be aware that your design may be subject to field modifications. A good example can be a ship's masts; I have seen masts intended to support only small (less than 100 lb [50 kg]) antennas, which have large walking surfaces for ease of access—just right for adding a 350 lb (150 kg) satellite antenna! What you end up with is an inverted pendulum, imparting extra motions into the satellite antenna at very low frequency.

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