Vibrating Equipment

Avoiding a Frequency Range

The purpose of a dynamic analysis will often be to avoid resonance between the structure and the equipment. For this purpose a frequent criteria will be that the natural period of the structure cannot be between 80% and 120% of the normal operating frequency of the equipment.

Ideally, you want to have a structure or foundation with a natural frequency greater than the operating frequency of the equipment. But, this is usually only possible if the speed of the equipment is less than 1000 RPM (16.7 Hz). When the frequency of the foundation or structure is less than the operating frequency then the equipment must pass through the resonant frequency of the structure during start up or coast down.

Calculating the Damped Frequency of the Structure

Structures that experience significant damping will experience resonance at slightly different frequencies that calculated based on analysis. The ratio between the damped natural frequency and the undamped natural frequency is the following:

$$f_d = f_n\sqrt{1-\zeta^2}$$

f_d = damped natural frequency

f_n = undamped natural frequency

ζ = zeta = ratio of critical damping

This will come into play later when we calculate the amplification effects caused by near resonance between our equipment and our structure.

Calculating the Unbalanced Force of Rotating Equipment

The unbalanced force is caused by an eccentricity between the mass centroid of the rotor and the center of rotation. The general calculation is the following:

$$F_o = m_r * e * \omega_o^2 * SF/12$$

F_o = Dynamic force amplitude

M_r = rotating mass

e = mass eccentricity

ω_o= circular operating frequency (radians / second)

SF = Safety facto to account for increased imbalance during service life of equipment

Typically, this information should be provided by the manufacturer o the equipment. There are ANSI and ISO industry standards regarding “well balanced” rotating requirement. Generally speaking, this means an unbalanced force of less than:

$$F_o = m_r * 0.25 * \varpi_o * SF \quad \text{(lbf)}$$

Response Amplification Due to Near Resonance

At resonance the undamped amplification response goes asymptotic. So, this is certainly something to be avoided. However, in cases where there the frequency is within 20% of resonance the amplification of deflections and forces can be calculated using the following equation:

$$\frac{X_{dyn}}{X_{static}} = \frac{1}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

$r = f / f_n$ = ratio between equipment frequency and natural frequency of structure

ζ = zeta = ratio of critical damping

For 2% critical damping, this amplification factor varies between 2.8 (at r = 0.8) to 25 (at r = 1.0) to 2.3 (at r = 1.2).

Alternatively, the expression can be simplified to ignore damping:

$$\frac{X_{dyn}}{X_{static}} = \left|\frac{1}{(1-r^2)}\right|$$

Reducing Response by Adding Mass

Not all dynamic equipment requires that a dynamic analysis be run. For relatively light equipment (less than 6 kips) which have a relatively low power rating (less than 200 hp), a dynamic analysis may not be required. All that may be needed is that the foundation contain sufficient size and mass to reduce the response. The more mass in the structure, the more energy it takes for the equipment to excite the structure.

For foundations with relatively light equipment, the required mass to limit the response will generally be between 3 and 4 times the weight of the equipment.

For elevated structures it may be more difficult to quantify exactly how much mass is required to reduce the response without running more complex calculations. However, the general concept of increasing both mass and damping is valid.