Vibrating Equipment

Avoiding a Frequency Range

The purpose of a dynamic analysis (eigen solution) is often to demonstrate that the structure and the vibrating equipment it supports do not experience resonance. For this purpose a frequent limitation 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 than calculated based on an eigenvalue analysis. The ratio between the damped natural frequency and the un-damped natural frequency is the following:

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

f_d = damped natural frequency

f_n = un-damped 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 (refer also to *ACI 351.3R-10*):

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

F_o = Dynamic force amplitude (pound force)

M_r = Rotating mass = Pound force / (386 in / sec2)

e = Mass eccentricity (in)

w_o= Circular operating frequency (radians / second)

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

Typically, this information should be provided by the manufacturer of 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 un-damped amplification response goes asymptotic. So, this is certainly something to be avoided. However, in cases where the frequency is within 20% of resonance the amplification of deflections and forces can be approximated using the following equation:

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

r = f / fn = 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:

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

The above expressions are derived for single degree of freedom systems. Even so, the basic concept is similar for multi degree of freedom systems. Therefore, the equation can be used as quick and dirty estimate to see how much a change in frequency will help or hurt the response. Or, how much a change in damping could help the response.

Time History Analysis

The formulas above can give an approximate response of the structure at near resonance. But, when you have deflection or velocity sensitive equipment then a more detailed estimate of the response may be desired. This would require a solution for the transient response of the system. In RISA this would be done with a Time History analysis. Predicting the response of a structure to vibrating equipment is probably the single most common reason for running a Time History analysis.

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), even an eigenvalue analysis may not be required. All that may be needed is that the foundation contains 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.

Notes: