Torsional Vibration Analysis

Torsional Vibration Analysis is the analysis of the torsional dynamic behavior of a rotating shaft system as a result of forced vibration. Torsional vibration, or twisting, is different from lateral vibration, or shaking. A torsional system, compressor, driver, and coupling, are modeled as a mass-elastic system (inertia and stiffness) to predict stresses in each component. Mass-elastic properties of the system can be changed by adding a flywheel (additional inertia), using a soft coupling (change in stiffness), or by viscous damping (absorb natural frequency stimulation). Not all systems require any modification to the mass-elastic properties to achieve a torsionally sound system.

Ariel Corporation can provide the data for the compressor necessary to perform a torsional vibration analysis. This includes the torque effort curves (torque versus crank angle), mass elastic data and fourier coefficients representing the torsional driving forces. The torsional analysis is the responsibility of the Packager.

Care must be taken to represent the operating conditionsthe unit will see, including any partial load conditions. Any single acting cylinder operation is important to include as these cases can represent the more dynamic torque effort curves.

When applying variations in speed and single acting cylinder configurations the torsional and acoustical response analysis will be much simplified by applying single acting configuration only at one given speed. In order to eliminate over complicating the torsional and acoustical systems, specific capacity control methods may be more attractive than others. For a discussion on these methods, and recommendations on capacity control methods, refer to the Capacity and Load Control topic.

Capacity control sequencing can be very important when considering single acting operating cases. Sequencing of cylinders for unloading can be very important to both the torsional analysis as well as the acoustical analysis. Single acting provides a much more aggressive forcing function for the torsional analysis. There is no absolute rule on which cylinders to single act at a time, but a recommendation is to **unload adjacent cylinders before unloading opposing cylinders** (unloading opposing cylinders is much more aggressive on the torsional forcing function than unloading adjacent cylinders). The opposite is true for acoustical analyses when considering single stage compressors with symmetrical pulsation vessels. These are recommendations for a more polite torsional solution, but not the only sequence that will work. A more aggressive load sequence, may just end up with a more aggressive solution to the torsional (black out speeds, torsionally soft coupling, larger flywheel...).

Once a load sequence is chosen, this needs to be applied to the torsional analysis, acoustical analysis, and the control panel logic sequence. If the unloading is to be by manual methods, such as removing valves, it is recommended to review load sequences for any possible variation single acting location.

When applying an electric motor driver, whether fixed speed or variable speed, specific attention must be made to the motor shaft design. The motor stub shaft and the section through the drive end bearing should equal or exceed the compressor drive stub diameter. JGE:K:T/6 and KBB:V frames have flanged drive end connections on the crankshaft, use the crankshaft journal diameter for the minimum motor shaft diameter.

ER-83 provides torsional analysis limitations and guidelines. Ariel provides Vibratory Torque Limits rather than allowable stress limits. Appropriate safety factor and fatigue method has been applied within these vibratory torque limits. Auxiliary end limits and guidelines are defined. Flywheel overhung weight limits are defined along with the proper calculation method.

The torsional analysis should be scheduled as early in the process as practical. Changes to the system design may be required to satisfy the torsional analysis. This may include a different coupling type or model, the addition of a flywheel, or on rare occasion a change to the compressor or driver design.

Below is a list of data necessary for the different phases of a project:

Quotation:

- System definition (compressor type / size, driver type / size)

- If electric motor, define if fixed speed or variable speed
- Include 4 to 7 operating points for review to characterize the full operational map (conditions and load steps) of the compressor

Purchase:

- Full system layout defining compressor, driver, coupling, speed control

Compressor Load Data:

- Define the full range of operating conditions
- Suction pressure range
- Discharge pressure range
- Load step sequence, including pockets and single acting
- Speed range
- Be sure to define load steps consistently throughout the case manager
- Be sure to provide the same load step sequence for the acoustical analysis and (if pneumatic capacity control devices) control panel logic

Compressor Data necessary for Torsional:

- Performance run file for the compressor defining the full operating map
- Mass elastic data
- Torsional supporting documents
- Performance report for each peak condition
- Gas analysis for each peak condition
- Crank effort curve for each peak condition
- Fourier coefficients for each peak condition

To Generate Data:

- Define the full operational map for the compressor in the Case Manager
- Define the Summary Field Configuration to include Peak-to-Peak/2 and Vector Sum 1 through 9 from the torsional section
- Run the Performance Summary and select the cases with the highest Peak-to-Peak/2 and Vector Sum 1 through 9

Run the Report Manager selecting the following reports:

- Configuration
- Mass Elastic Data
- Torsional Supporting Docs
- Performance
- Gas analysis
- Torque Demand Graph
- Fourier Coefficients

Confirmation:

Confirm Torsional recommendations against equipment on order or shipped. This includes confirmation of:

- Flywheel size
- Coupling model
- Internal flywheel size
- Detuner quantity and location
- Driver dampener

Confirm Torsional solution through field verification at start up for larger, more complicated and new driver compressor combinations, including

- Large Electric Motor Drives
- Variable Frequency Drives
- New Combinations of Driver / Compressor
- Complex Torsional Designs (black out speeds, torsionally soft couplings, black out load steps)

Documentation:

- Recommend including the Torsional Study report in the unit records book for the end user and jobsite