Specification for Centrifugal Compressor Piping System Vibration/Dynamic Analysis

(Surge Control Dynamic Study, FIV, AIV, Pipe Stress Analysis)

This Piping Vibration Specification includes the following:

1. Supplier Qualification
2. Surge Control Dynamic Design (Dynamic Simulation of Compressor/Piping System)
3. Flow-Induced Vibration (FIV) Assessment
4. Acoustic Induced Vibration (AIV) Assessment
5. Optional Studies:
    a. Pipe Stress Analysis (thermal piping analysis)
    b. Small Bore Connection Assessment (evaluation to avoid resonance in branch connections)
    c. Pulsation Interaction with Reciprocating Compressors (analysis of pulsations in the piping system and potential interaction between reciprocating/centrifugal compressor systems).

Tips for Successful Projects

The goal of the work is to avoid vibration-induced piping failures (integrity problems) or reliability problems. Best results are achieved when the facility owner or engineering consultant contracts directly with the Vibration/Dynamic Design Consultant to perform the studies. This ensures the work covers the required scope and avoids potentially conflicting roles and recommendations.

Best practices for successful projects include early involvement, typically at the Front End Engineering and Design (FEED) stage and during the detailed design phase.

1 Supplier Qualification

The supplier shall be an established vibration/dynamic design and field engineering company. The following capabilities are required (no deviations permitted):

- The supplier’s engineers shall have over 10 years of experience working with dynamic simulation of centrifugal compressor systems and reciprocating compressor systems, and in pulsation analysis, flow-induced vibration, piping flexibility, structural dynamics, and torsional vibration analysis.
- The supplier owns transient and pulsation analysis software, based on the method of characteristics. The supplier has field verified the accuracy of its software and can provide its own field test results to verify the accuracy.
- The supplier has full time field engineers on staff with experience in field performance testing, multi-channel spectral vibration analysis, and documented field troubleshooting experience in FIV, AIV, shell mode, and small bore analysis.
- The Supplier provides technical training courses on the related topics.
- To ensure consistency, all of the following studies are to be performed by the same supplier.

Beta Machinery Analysis is an approved supplier for this scope of work.

2 Surge Control Dynamic Design (Dynamic Simulation)

A dynamic transient study is required for the centrifugal compressor surge control system including every stage of the compressor, associated suction and discharge piping, recycles line(s), affected coolers, check valves, and related control components.

The scope of the study shall include all three of these compressor operating scenarios:

a. Start-up
b. Operations including all standard operating conditions and planned shutdowns
c. Emergency Shutdown

The supplier shall use field-validated transient analysis software capable of transient surge analysis. The software shall include the full governing equations describing transient compressible flow in piping systems solved by the method of characteristics using partial differential equations and includes the spatial gradients.

CENTRAN transient software is approved for this application.
Beta Machinery Analysis is an approved supplier for surge control design analysis.

The following information is to be supplied and utilized in the transient model to ensure sufficient accuracy of the surge control system:

a. **Compressor, Gearbox and Driver** Supply manufacturer, model, and ratings. Supply information about gearbox if included. Include information for each stage of compression, if required.
b. **Isometrics, P&ID, and General Arrangement drawings** Include drawings of the compressor installation, coolers, and piping system. Include drawings of other compressors in the station including reciprocating compressors.
c. **Application** Summarize application, operating requirements, including any unique features.
d. **Compressor Flow Map** Map is to be in terms of polytropic or isentropic head versus actual flow. Include factory test verified surge control line (if available).
e. **Gas Composition** This is the range of expected densities/compositions.
f. **Inlet Volume**
g. **Discharge Volume** Provide the volume on the discharge system to check valve including recycle line, associated cooler, etc.
h. **Start-Up Time** (seconds) This is the total time the unit can operate in recycle mode before overheating.
i. **Rotating Inertia** This is the inertia of the driver component and connected load.
j. **Delay Time to Shut-Off Driver Power** Driver OEM shall provide the estimated time to reduce all power to compressor based on the driver response time. For example, most electric motor driven machines will quickly shut off all power to the compressor. The response time is often < 2 seconds.
k. **Delay Time Due to Control System Response** The response time shall include turbine unloading, lag time between the fuel shut-off and the control valve.
l. **Valve Response** Provide information on valve stroking times and additional dead time for all valves in the system including isolation valves.
m. **Estimated tuning/configuration parameters** Estimate for the surge control system includes estimates for step opening of anti-surge valves.

Study Requirements and Deliverables

a. **Initial Review** The vibration engineer shall review the compressor application, proposed operational requirements, preliminary piping, and other available information early in the project (including Front End Engineering & Design stage if possible). Vibration engineer to provide recommendations and considerations.
b. **Detailed Design**
    i. The vibration engineer shall prepare an accurate transient model based on the design information.
    ii. The model shall include all tolerances, including control system delay, actuator timing, valve operation, etc.
    iii. The model shall analyze the start-up, operations, and emergency shutdown. The operating scenario shall evaluate the entire operating map.
    iv. Risk areas shall be identified.
    v. Modifications shall be identified and evaluated.
    vi. Detailed report shall be provided that summarizes the model parameters, recommendations, and model results.

3 Flow-induced Vibration (FIV)

This study evaluates vortex shedding and potential vibration across dead leg branches, and also focuses on FIV excitation of small bore attachments such as thermowells and other components in the flow.

a. Evaluate all dead leg branches in the compressor system including suction and discharge piping.
b. Determine acoustic natural frequency (ANF) for each location in the system.
c. Identify excitation frequencies and locations where resonance with the ANF is possible.
d. Review drawings and standards for thermowells and other components inserted in the flowline.
e. Evaluate design to determine risk of fatigue failure.
f. The report shall include findings and recommendations to address FIV risks.

4 Acoustic Induced Vibration (AIV)

This study evaluates acoustic energy downstream of pressure reducing valves, safety valves and other pressure reducing locations. AIV can generate large amplitude vibration in the main process piping and branch connections.

The study shall evaluate the piping system, identify AIV sources and high risk areas, and recommend modifications to the piping system, valves or other solutions to reduce dynamic stress levels.

The Eisinger (also referred to as D/t) method shall be used to check piping against fatigue failure limits based on the calculated sound power level (PWL).

5 Optional Studies

a. Pipe Stress Analysis

i. The main discharge process piping shall be included in the scope of analysis. The client shall define the piping system to be evaluated.
ii. The model shall be terminated either at an anchor point (which must have a stiffness and order of magnitude higher than adjacent supports), or at a point significantly far away from the edge of scope to avoid influencing the results.
iii. Cooler nozzle loads shall be evaluated against API 661, or other field-proven guidelines. Vessel nozzle loads may be evaluated against WRC 107, or other field-proven guidelines.
iv. Boundary conditions shall be accurately modeled with appropriate stiffness, gaps, and friction. “Anchor” or “rigid” boundary conditions are typically not appropriate and result in excessively conservative recommendations.
v. The report shall contain the findings and recommendations.

b. Small Bore Connection Assessment (evaluation to avoid resonance in branch connections)

i. Small bore piping (PSVs, relief lines, drains, sight glasses, etc. - typically NPS 2 or less) shall be evaluated for risk of fatigue failure.
ii. The standard design service shall include:
    - At the design stage, small bore piping shall be evaluated for likelihood of failure (LOF).
    - During fabrication, visit the shop to conduct impact test, visual inspection, and evaluation of small bore piping.
    - After start-up, a small bore piping vibration audit shall be conducted and compared to field-proven guidelines.
    - The report shall include design of mechanical recommendations to mitigate risk of fatigue failure.
iii. Refer to SBC Assessment service for more details

c. Pulsation Interaction with Reciprocating Compressors

i. This study is recommended where multiple reciprocating compressors are connected on the same header as centrifugal compressors. Pulsations generated by reciprocating compressors can affect the reliability of centrifugal compressors.

ii. The scope of analysis is to evaluate pulsations in the headers and piping system, which can interact with a centrifugal compressor.

iii. Non-linear Time Domain pulsation analysis software shall be used to evaluate pulsations generated in the suction and discharge headers. The study shall compare pulsations from different combinations of compressor operations (operating vs shut-in) and to address different operation pressures and flow rates (based on planned or actual operating history).

iv. Worst case pulsation amplitudes and forces shall be identified. Determine operating scenarios where the pressure pulsations will exceed the tolerances of the centrifugal compressor. If problems are predicted, recommended modifications or further actions necessary for ensuring reliable compressor operation shall be provided.

v. Report shall contain the findings and recommendations.