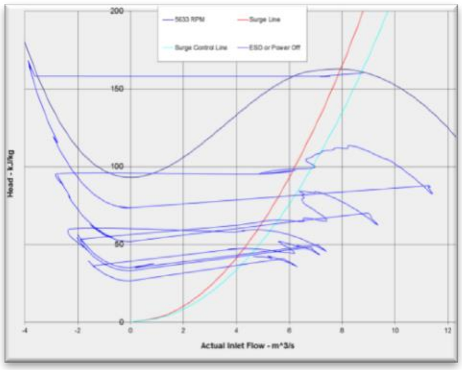
Surge Control Design for Centrifugal Compressor Systems

This Dynamic Simulation study is recommended for new or modified compressors, especially low inertia systems. The simulation evaluates all operating scenarios and recommends the optimal surge control strategy in order to improve compressor operations and prevent damaging surge events.



ESD Surge Event (illustrating 5633 RPM compressor instability during surge)

Centrifugal Compressor Damaged During Surge Event

Background

During a surge event, the centrifugal compressor system must cope with large flow and pressure transients. The transients can occur during startup, normal operations, emergency shutdown (ESD), or fast stop. This S*urge Control Design* study evaluates the system dynamics and makes recommendations to avoid operating or reliability problems.

During surge, the centrifugal compressor interacts dynamically with system components around them, i.e., piping, fittings, valves, and rotating equipment.

Fluid inertias and compressor/driver rotor inertias play an important role in either stabilizing or destabilizing the system dynamics. The compressor's performance characteristics also have an important role in the system dynamics' behavior.

Furthermore, the recycle system around the centrifugal compressor unit is an essential component in the unit's operation. It is necessary for startup, shutdown, surge protection and flow control (turndown capability). As these operations are transient in nature, all dynamic parameters from gas flow, equipment, and control, play an important role and impact the system instabilities, performance, and safety.

This study involving transient modeling is the preferred approach for designing a new (or modification to an existing) compressor system.

Factors Affecting Surge Control Design

The parameters that affect the potential for the compressor to undergo surge during ESD are the recycle valve characteristics such as maximum capacity, flow vs. opening characteristics, opening delay (i.e., the time between valve open solenoid drop out and the start of the stem movement on the valve – often called 'pre-stroke' delay), and valve travel time (i.e., the time taken for the valve to travel from closed to open positions – often called 'stroke' time).

Additionally, timing of the compressor ESD signal, the fuel gas shutoff signal, fuel gas manifold size (in case of gas turbine drivers), power train inertias, and compressor aerodynamic characteristics close to surge point, all contribute to the complexity of the problem.

Finally, gas and equipment dynamic interactions of other elements employed in compression systems, such as check valves, relief valves, and blowdown systems, are also important and have to be investigated. This leads to mechanical stress analysis, thermal analysis and suction and by-pass valve design and selection criteria.

Applications Requiring Dynamic Study

A dynamic study is applicable to low inertia systems (including the combined compressor/driver rotor system). These compressors are typically driven by electric motors or aero derivative turbines and used in pipeline transmission, gathering, and injection applications. Centrifugal compressors used in industrial applications, including steam turbine units, generally have high inertia and are less prone to surge problems.

Compressor OEMs can provide inertia data for the wheel (impeller), rotor and driver.

For application questions, please contact BETA.

Scope of Dynamic Simulation Study

The scope of this dynamic study includes these steps:

1. Recycle system. Assess the recycle system capacity with respect to the compressor wheel map. Confirm the size/capacity (adequacy) of the system for the steady state operating range. Includes modeling the compressor, piping system and valve characteristics.
2. Start-up protocol. Assess the system Start-up sequence and evaluate discharge temperature versus time.
3. Normal shutdown protocol. Assess the normal shutdown protocol to evaluate the valve shutdown sequence, timing, rates, and the ramp down of the driver (turbine, motor, engine, etc.).
4. Slow Transients Analysis. Provide independent check of the compressor surge control protocol during slow transient events, such as, inadvertent closure of suction and/or discharge valves (e.g., accidental shutdown).
5. Fast Transient Analysis. Due to ESD, fast stop or power failure, evaluate the entire system and effectiveness of recycle system in severe dynamic conditions.
6. Evaluate interaction between units (if multiple compressors share the same gas path and station piping in series or parallel arrangements).
7. Evaluate additional “what if” scenarios that are often requested by the owner or engineering consultant.

The deliverables include recommended changes to the control logic, recycle strategy, and other parameters, and report defining surge control characteristics during upset conditions and across the operating window.

The study can be performed in the FEED stage, or early in the detailed design stage. This provides sufficient time to review the design and provide recommended modifications.

BETA Experience and Representative Examples

This service is led by Dr. Kamal Botros, a Sr. Associate with BETA. Dr. Kamal Botros is a world authority on surge control design and analysis and has focused his research activities on transient flow problems in complex systems, including centrifugal compressor surge phenomenon, pressure relief system dynamics, transients of two phase stratified flows, interface mixing between batches in pipelines, fluid-structure interactions and flow induced vibration in heat exchangers. Dr. Botros has published over 170 technical papers in Journals and refereed conferences. Representative examples include:

- Dynamic analysis of 17 compressor stations on major pipeline system.
- Recycle system dynamic analysis of 5 compressor stations on TransCanada Pipeline system.
- Dynamic analysis of gas processing train including LP, IP, HP and Injection compression system in series.
- Dynamic analysis of a wet gas, hydrogen sulfide (H2S) rich gas six-stage centrifugal compressor of a Fractionator in a Coker Unit.
- Dynamic instabilities of high head centrifugal compressors and cold recycle system leading to compressor and nozzle type check valve damages.
- Dynamic analysis of 6 impellers, 3.5 pressure ratio Solar C-306 Compressor Surge Protection System.
- Dynamic analysis of three stations incorporating Solar Titan T130S Gas Generator and Solar C652 compressors.
- Dynamic analysis of pumping systems for a power plant condenser system.
- Dynamic analysis of a Heat Exchanger Tube Rupture Discharging a High-Pressure Flashing Liquid into a Low-Pressure Liquid-Filled Shell.
- Dynamic instabilities of two parallel integral superheaters to vaporize NGL feed to olefin cracking furnaces.
- Dynamic analysis of the relief system of a gas gathering battery including two compressors, 2 dehydration units, and an inlet separator.

CENTRAN Software For Dynamic Simulations

BETA utilizes a dynamic simulation tool called CENTRAN. This dynamic model was developed by Dr. Kamal Botros after two decades of experimental and numerical investigations. CENTRAN has been validated against field data and experimental setups.

The solver is based on the method of characteristics for the solution of the full governing one-dimensional equations of gas flow including the energy equation. CENTRAN is effective at analyzing numerous transient and unsteady problems.

There are important differences between CENTRAN and commercially available simulators such as HYSYS® Dynamics (Aspen) and DynSim Design®). The limitation of these commercial software packagers is that only the time gradients are considered in the dynamic simulations (i.e., <u>temporal</u>), which amounts to describing the dynamics of a system using ordinary differential equations (ODEs) that are much less rigorous than partial differential equations PDEs. This is referred to as the “lumped parameter” method which gives a solution that is a reasonable approximation of the distributed model solution. This approach <u>is not adequate</u> for dealing with compression dynamics involving recycle systems and surge phenomenon of compressors going into and out of surge.

The <u>spatial</u> gradients along the length pipe segments around the compressor unit are crucial as they determine the time taken for pressure, flow and thermal perturbations to reach one point in the system from another point (e.g., source of the disturbance).

The developed model (CENTRAN) is based on the solution of the full PDEs, and is considered as a distributed parameter based model, i.e. does not ignore the <u>spatial</u> gradients.