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Turbomachinery Control System Design Objectives



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The primary design objective for any turbomachinery control system should be to maintain or maximize machine and associated process reliability. With this assurance firmly in place, attention can then be turned to maximizing machine and process efficiency.

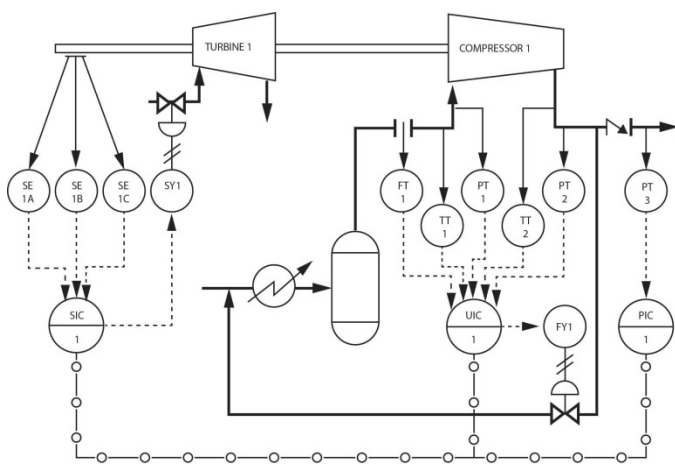
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Machine and Process Reliability

A well-designed turbomachinery control system should take into account typical, as well as, rare types of process disturbances. Analysis should be made of the size and direction of these disturbances and how they will be “felt” by the turbomachinery train in both a static and dynamic sense. Process disturbances are mostly associated with so called “pressure waves” from the suction or discharge network of the compressor.

However, disturbances in the process stream or gas composition can be just as dramatic in their effect on compressor control as changes in pressure/flow rates.

Many process control professionals begin with the notion that process reliability is tantamount to machine reliability goals such as compressor antisurge control, load limiting, high and low pressure limiting, overspeed prevention, etc. This notion is quickly lost however when, for example, a compressor surge incident causes a machine to trip, bringing down the associated process. In many processes, a surge incident can also create enough process oscillation to initiate a process trip prior to high temperatures and/or train vibration initiating a machine trip. It should be readily apparent that turbomachinery almost always operates as the “heart” of the process and that it then becomes impossible to separate machine and process reliability.



Picture 1: Simplified control system diagram for a steam turbine driven centrifugal compressor

The effectiveness of any control system is influenced by all associated control elements, including primary measuring elements, transmitters, control valves, and actuators, process vessel locations and process piping configuration. The fastest and most accurate control system cannot function optimally with noisy input signals; slow or dysfunctional control valves, or unnecessarily large process lag times. It is particularly important when dealing with the high speed of approaching surge found in many applications, that the speed and accuracy of the response of all antisurge control loop elements is examined and addressed.

Speed control functions should be integrated with coupled process control loops to enable automatic tracking features and simplified mode switching in order to minimize requirements for operator involvement particularly during critical times of start-up and shutdown procedures.

Overspeed trip scenarios in turbine applications are not only safety concerns, but unnecessary trips are also quite obviously machine and process reliability concerns. In the case of turbo-compressor drives, surge incidents (sometimes referred to as “slipping the load”) can cause turbines to accelerate rapidly to dangerously high speeds and potentially overspeed trip situations. Some algorithms have been developed for integration between antisurge control and speed control systems in order to head off turbine overspeed and overspeed trips when a compressor surge condition is detected. Of course damage from overspeed occurrences and trips can cause extended process outages.

As we have touched on above, the prevention of surge in centrifugal and axial compressors is extremely important in maintaining process reliability. While the flow reversal from a single surge cycle will cause a “shock wave” through the process, multiple surge cycle incidents left unchecked will inevitably necessitate a unit shutdown due to undesirable and possibly dangerous process or machine conditions. Multiple surge cycles can cause the gas stream temperature to rise at an exponential pace as the hot gas in the discharge is pulled back through the machine and subsequently recompressed over and over again. Compressor damage caused by the thrust

reversals and high temperatures created by surge cycles will reduce compressor efficiency and in severe incidents can necessitate unscheduled machine and process outages.

Turbomachinery control system design should include special provisions for startup and shutdown operations. This includes standardized and coordinated ramping procedures both for normal and emergency scenarios, continuous machine monitoring for abnormal conditions and automatic starting aborts, etc. Advanced automation techniques have proven successful in making the intelligence, and the experience, of the most capable operations personnel available at every unit startup and shutdown. With automated startup and shutdown systems in place available operators can be concentrating on other potentially less predictable areas of concern. Although antisurge valve ramping is recommended for startup and shutdown automation, it is also important to maintain the integrity of the proximity to surge and surge detection algorithms for override purposes during any valve ramping procedures.

Accurate and stable speed control is also critical to the success of any turbomachinery control system in a variable speed application. As with compressor control, excellent turbine speed control is also very much influenced by the speed and precision in the movement of the steam valve(s) on steam turbines and in the actuation of the fuel valve in gas turbine applications. Care should be given to maximizing actuator speed of response with stability and minimizing valve “stick-on” and hysteresis.

Machine and Process Efficiency

When you consider that a 3,000 horsepower mechanical drive unit costs the user an excess of \$1,000,000 worth of energy a year (at less than an equivalent \$.05/kWhr) it becomes clear that energy efficiency should be a key component in any good turbomachinery control system design. More importantly, process efficiency can be directly related to precision of turbomachinery control; i.e.: precise turbine speed control, advanced antisurge control, integrated process limiting variables, etc. As power draw is proportional to speed, possibilities to reduce

turbines (when process conditions allow), even in small amounts, should not be overlooked. The goal is to meet all process requirements while operating at the lowest possible energy level.

In turbocompressor applications, much attention is given to minimizing antisurge recycle (or blow-off in the case of air compressors) as process gas that is being recycled or released to atmosphere represents an overproduction of compressed gas. This “overproduction” can potentially be reduced through further speed reductions and/or deeper compressor inlet throttling; however, turbo-compressor throttling is limited by the thermodynamic capability of the compressor to produce the head requirement necessary to maintain process flow under low load conditions.

A good antisurge control system design will work to minimize overshoot from the antisurge control line and maximize compressor stability during process upsets, thereby reducing the safe margin requirement in the antisurge setpoint. Minimum safe margin in the antisurge control system equates to a maximized operating envelope without wasteful recycle or blow-off. By moving the antisurge control line as close as possible to the actual compressor surge limit, it is also possible to move up the compressor performance curve and produce higher discharge or lower pressure when it is an advantage to process efficiency.

Turbo-compressors are often arranged in parallel or series configurations in order to add system flexibility and or reliability. Some installations have grown into multiple compressor operations as process requirements (capacities) have increased over time. In all of these scenarios, an optimally designed turbomachinery control system should include some provisions for automatic loadsharing between compressors and turbines.

Optimized Compressor Loadsharing

In a turbo-compressor loadsharing system, the primary process control variables and limiting loops become the master control system working through some type of loadsharing system that is directly connected to the turbine speed setpoints or

compressor inlet throttling devices. The question now becomes, on what basis should the load between compressors be divided. The system designer has to take into account that none of the machines has an unlimited efficient operating envelope as dictated by the surge limit, process limits, and the thermodynamic limitations of each compressor. The designer also needs to be aware that even identical compressors will very rarely demonstrate identical characteristics in the field. This is due to slight differences in manufacturing differences in piping layout, etc. Differences in surge limits mean that with equalized flow division users can end up with one machine in recycle or blowing off with others working out on their compressors maps. In parallel operations differences in head producing capability means that running with equal speed or throttling may leave users running at less than optimal suction or discharge pressure production. Clearly the optimal loadsharing system would balance compressor loading based on an online calculation of distance from surge at low loads, would work to minimize energy consumption at mid-level loads, and work to maximize head production under high demands for compressor head.

Control System Reliability

A preliminary level of hazards and operational analysis and/or a process control system layer of protection analysis should be done at the onset of the design of a turbomachinery control system. During this process, the system designer should work to determine the functionality and proper placement of system flares; relief valves, check valves, and recycle take-off points (for turbo-compressor applications). Care should be taken to ensure adequate system cooling capacity for all levels of operation. For compressor applications, the cooling load under conditions of 100% recycle needs to be considered. Responsible parties should also make decisions relation to:

- The implementation of automatic fallback strategies to provide continued operation in the face of a lost input signal or the simultaneous loss of multiple input signals
- A target system availability figure and the appropriate level of redundancy to be

implemented for field and control room instrumentation

- UPS (uninterruptible power supply) system strategy to be applied (if any)

The specifics of field instrumentation specification as well as the selection of control system initialization parameters should be thought through from the point of view of safe and reliable turbomachinery control and protection.

Conclusion

Turbomachinery control system design presents one of the most interesting and demanding application in the process control field. The successful turbomachinery control system designer should work closely with user representatives from other integral disciplines, including process engineering, mechanical engineering, as well as with operations management in the design and specification of an optimized control system for this application. Due to the extremely critical nature of the continuous operation of turbomachinery (particularly in the process and oil and gas production industries), proper system design is critical in providing safe, reliable, and efficient machine and process operation.