

Control and Condition Monitoring of Reciprocating Compressor

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Optimum configuration for control system, instrumentation, electrical and condition monitoring of reciprocating compressor is presented. Reciprocating compressors are most flexible and most efficient available compressors. Recommendations regarding inter-stage pressure control, capacity control system, temperature control, performance monitoring, local control panel, irregularity and condition monitoring are discussed.

Installed reciprocating compressor horsepower is approximately three times that of centrifugal compressors and maintenance costs of reciprocating compressors are approximately three and half times greater than those for centrifugal compressors. The expected level of reliability and availability of reciprocating compressors is very high and it presents a real challenge. Advanced methods of control and condition monitoring shall be applied in order to obtain the high level of performance, safety and reliability.

Reciprocating Compressor Control

Reciprocating compressor arrangement is often complex and compromise must be made between process requirements, vibration conditions, control requirements, operation, access and maintenance. Optimum configuration is to install local panel near compressor package (around 200 mm away from package) but on separate skid (frame) which is installed on foundation, to avoid vibration damage. Special purpose units are generally installed under shelter, however, design and selection of instruments, electrical, monitoring, control components and sensors are for "Outdoor".

The system layout shall be such that all system components including locally mounted indicators, switches, controllers, transmitters, etc, are easily accessible for operation and maintenance purposes. Indicators throughout the system shall be easily legible from the sides of the console. Flanged connections shall be provided to facilitate assembly or removal of instrument, equipment and piping without need to remove other system components. For hydrocarbons, threaded connections are not recommended both for piping and instrumentation.

Sometimes, due to process requirements, reciprocating compressors shall be capable to operate at a wide range of suction pressure and conditions to deliver a defined flow and discharge pressure. It can have strong effect on electric motor sizing (for reciprocating compressors more than 35% driver power increase for operation in case of 20% suction below normal) and control system. It is necessary to respect all

process conditions at early stage of design to avoid costly modifications and changes in future.

Some reciprocating compressors are designed to operate with alternative gas (for example process gas compressor to compress nitrogen in plant start up). Compressor shall be designed to work with alternative gases without changing any hardware. Alternative gas operation (such as N₂ start-up case) shall be designed to give similar discharge temperatures to the normal operating case, allowing the existing discharge temperature trips to safeguard the compressor and avoiding relying completely on the relief valves.

Optimum inter-stage pressures can be obtained by formulation and optimization of performance and investment for compressor and inter-stage facilities. Some vendors are intended to change inter-stage pressures, generally higher pressures at early stages and lower pressure ratio at last stages. Vendor offered inter-stage pressures based on just compressor without respect to inter-stage facilities, are not justified. Inter-stage pressures are going to increase during part load operation and high suction pressure. If not tolerable, additional clearance pocket on first stage cylinder and part load operation inhabitation by the controlling logic can be studied. Generally it is compromise to fix inter-stage control setting pressures (and also inter-stage facility design pressures) based on increased inter-stage pressures due to part load and suction variation. Control setting pressures are around 12-15% higher due to common ranges of part load operation (five step capacity control) and suction pressure variations (around 7-9% variations).

Step-less capacity control system uses finger type unloader, is hydraulically actuated, and unloads the suction valve for only a portion of compression cycle to achieve adjusted capacity. Finger type unloaders have potential for damaging the valve sealing elements and require more care for maintenance. Valves and unloaders cause around 44% of unscheduled reciprocating shut down and this selection has a strong effect on reliability. For small machine, 100% spill back is optimum solution, because power is low. For big machine optimum configuration is selection of part load steps based on plug/port unloader and clearance pocket.

There are many compressor packages purchased with incomplete instrument and control system documents. Optimum instrument and control document list is as follows: Instrument list, Instrument specification (or instrument data sheet), cable list, junction box wiring diagrams (field wiring diagram), instrument lay out (electrical plant arrangement), cause and effect diagrams, plant starting up and shutting

down procedures (starting and stop sequence), logic schematic (functional logic diagrams), local control panel wiring diagram and setting points (in instrument list).

Reliability and Safety

Condition monitoring shall be particularly cost effective and include necessary items to identify malfunctions at an early stage (lower maintenance costs and lower risk of accidents). Optimum vibration monitoring: 1- Vibration – continuous monitoring (Alarm and Shut down). Velocity transducers are preferred over accelerometers due to better signal to noise ratio. The optimum configuration: each end of the crankcase about halfway up from the base plate in line with a main bearings. 2- Each cross head accelerometer (Alarm). 3- Electric motor vibration (Alarm and Shut down).

Optimum temperature monitoring: 1- High gas discharge temperature - each cylinder (Alarm and Shutdown). 2- Pressure packing case - piston rod temperature (Alarm). 3- High cross head pin temperature (Alarm). 4- High compressor main bearings and motor bearings temperature (Alarm). 5- Valve temperature (Monitoring). 6- Oil temperature out of frame (Alarm). 7- High jacket water temperature - each cylinder (Alarm). Optimum implementation is properly set trip levels that are just high enough over the normal operating levels to avoid mechanical failures, but not so high as to miss the failure prior to catastrophic release. Proximity probes are typically located under the piston rods and used to measure the rod position and determine wear of the piston and rider bands, malfunction e.g. cracked piston rod attachment, a broken crosshead shoe, or even a liquid carryover to a cylinder. Optimum figure: just for alarm and not for shut down. Optimum cold run outs and normal conditions operating run outs are about 50 microns (2 mils) and on the order of 50 to 150 microns (2 to 6 mils) peak to peak, respectively. All shutdown functions shall be 2 out of 3 voting to avoid unnecessary trip. Usually it may be deviated for compressor frame vibration and machine temperature related trips.

Sometimes odd number of cylinders is not avoidable. In these cases, dummy crosshead shall be used. Also spring-mass-spring system shall be studied for passive vibration control (force counter balance), where dummy crosshead is, on the one hand, flexibly attached to a movable piston assembly and on the other hand, to the stationary compressor casing using auxiliary mechanical springs.

For all reciprocating compressors, flywheel is mandatory to regulate variable reciprocating torques. Irregularity degree less than 1% is recommended for special purpose units (Optimum value around 0.8-1.2%).

High discharge temperatures cause problems with lubrication cooking and valve deterioration and shall be controlled strictly. The maximum predicted discharge temperature shall not exceed 150°C and not exceed 135°C for hydrogen rich service (MW of 12 or less). Gas discharge temperatures less than 118°C tended to extend life of wearing parts. It is optimum figure.

A review of the steepness of the load curves can quickly identify which load steps (and where) are quite steep in nature, and thus small changes in pressure can have significant changes in load and flow. Often, steep load curves may indicate improper sizing of cylinders and units with steep load step curves can also prove difficult to control, automate and tune.

Case Study

Presented approaches are implemented for a four throw and three cylinders heavy duty reciprocating compressors for hydrogen make up refinery service. Figure 1 shows compressor brake torque in one shaft revolution (from less than 20% of motor rated torque to around 170% of motor rated torque). It shows importance of flywheel to regulate train torque requirements. Only with proper control and condition monitoring, working in these ranges of high rod load is possible.

Based on operation experiences and extensive studies, presented approaches for control and condition monitoring provide maximum productivity and minimum unscheduled shut down. These results can increase unit capacity from less than 92% to more than 96% of rated unit capacity. For this reciprocating compressor unit, it yields to more than 450,000 USD annual benefits in more production and power saving in addition of maintenance savings. For a typical heavy duty reciprocating compressor unit in refinery service (for example in the middle size make up hydrogen reciprocating compressor unit) each day of shut down means more than 190,000 USD loss of profit.

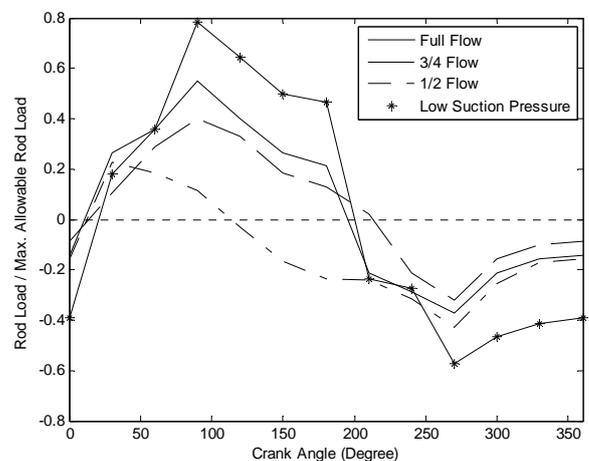


Figure 1: Rod load curves for various operating conditions of reciprocating compressor.

Conclusion

An integrated approach on reciprocating compressor control, instrumentation, condition monitoring and electrical system has been presented. It presents answers about purchasing new unit or upgrading existing units for maximum reliability, safety and minimum power consumption.