Direct Query: Compressor Control, Load Sharing and Anti-Surge

S M Kumar
Process Design Consultant
Top Contributor

Note: Please post such queries to forum. As you have seen the discussion in pressure equalization, there are multiple view points and you should benefit from them.

I am posting a summary of response to a number of queries and then responding to a few queries. Hopefully others can pitch-in to give a well-rounded response.

Unfollow S M

Please read first the section on Compressor Control System in GPSA Chapter 13. Capacity control and Surge Control are 2 distinct issues.

Capacity Control: in Oil & gas plants you wish to pump out whatever gas that comes in. This is achieved by keeping constant pressure at the source vessel like Production Separator. The d/s compressor runs on maintaining its suction or source vessel pressure constant via a suction manifold PIC control. Its changes the speed in variable speed compressors run by gas turbines. In constant speed compressors run by electrical motor the suction PIC throttles a Suction Throttling Valve (STV). Compressor at a given speed is a constant volume machine. By throttling, you maintain the same suction volume (ACFM/ICFM) flow but at a lower suction pressure/ density; mass flow is reduced to match inflow. Head developed is reduced due to lower inlet density. Clear? Read again and look at GPSA Figure 13-48 and 13-50.

If you pump out less than what is produced, mass will accumulate in the source vessel, increasing its pressure. The suction PIC will speed up the machine or throttle less. If more gas comes than that can be handled by maximum speed or no throttling, gas accumulation in suction will increase beyond suction PIC set pressure. A second PIC/PCV at suction will dump the excess gas to flare. This second suction PIC dumping to flare is set at slightly higher pressure than the first PIC controlling the compressor. Note: During such a scenario, compressor operates at a suction pressure higher than its normal suction pressure. If inflow is reduced, speed is reduced or suction is throttled.

Reducing speed or throttling suction reduces discharge head. In most of the oil & gas applications, the suction and discharge (glycol contactor or pipeline?) pressure remains the same; Thus there is a minimum speed or maximum throttling beyond which you can't go. Otherwise you will meet the head required. See GPSA Fig 13-48 and 13-50. If the inflow is lower than achievable by min speed / max throttle, then you use an overall recycle line that sends cooled compressed gas from discharge header to suction header. Thus compressor capacity control is achieved by Suction PIC and overall recycle.

Discharge override: At times what is pumped out may exceed what the user wants. If there is a pipeline in between, you can pack it to its maximum operating pressure. If the discharge pressure keeps increasing, a PIC in discharge manifold will override the suction PIC, takes over compressor control and slow down the compressor or pinch suction. This will increase the suction pressure and gas will be dumped to flare.

Compressor Anti-Surge protection: Whenever there is sudden drop in discharge flow as a result of discharge PCV throttling, if any, or closure of a large downstream user, the discharge PIC will try to slow the compressor. Due to inertia, it will take time to slow down the large rotating mass to match system demand. But system pressure pulses travel at high velocity that can result in surge or flow reversal damaging the compressor - its seals, bearings and internal blades in seconds. Anti-surge valves are fast acting, open fully in 0.8 to 2 seconds and dump gas from discharge to suction to increase the suction flow the compressor and move away from surge. Capacity control is not by anti-surge valve. Anti-surge valve (ASV) is for machine protection. Some compressor supplier consider even ASV is too slow and want a second hot gas bypass, an on/off valve that will send hot discharge gas back to suction with minimum piping.

End of Part 1

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S M

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Part 2
Capacity control by recycle and Surge Control are 2 different tasks. In certain compressor configurations it is difficult to give an overall recycle and in these cases, ASV acts as capacity recycle control. While some operators insist on 2 separate valves, some do not mind using anti-surge valve for capacity control and run machines for days on total recycle.

Load control. Load control comes in when there is more than one compressor train. There are two approaches – (1) you run all duty trains at more or less equal load, taking care that all are equally away from surge line, that is right of the surge curve. Surge behaviour of identical trains could be different (2) Some operators prefer to operate only one train on swing load or variable load; they operate the rest of the duty trains at fixed constant load on manual control as it is supposed to increase machine life. They periodically change over the swing trains to manual and switch another train to swing load. The swing load machine maintains constant suction pressure as explained above until discharge PT/PIC overrides, if required.

Whenever a running train in a multiple compressor train trips, the suction pressure will shoot up and PIC will try to speed up the machine(s) on speed control or open the suction throttling valve in motor driven units. It can overload the still running machine. In GT driven units, governor will limit the speed. In motor driven units, high current will override the suction PIC and pinch the suction throttle valve (STV) to limit flow thru the running train. Otherwise, all the running trains will trip. STV throttling will result in suction dump to flare. These aspects on system response – are usually studied under the various Dynamic Simulation scenarios, mentioned in my previous mail.

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S M

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Part 3
Q: What are role of suction and discharge PTs. Why high power/current override is not shown in P&ID.
R: Suction and discharge PT + inlet flow helps supplier determine the operating point and as input to Anti-Surge control. Usually high power/current override is NOT shown in P&ID as it is part of the black box given by compressor vendor with only outputs to STV (Suction Throttle Valve). Good idea to look at all the black box signals that interfere with your P&ID and mark them in your P&ID, by looking at compressor vendor control logic with the help of your Instruments Engineer. Show a separate arrowed line to STV marking it “High current/ power override”

Q: Discharge pressure override. Is it an additional instrument in addition to anti-surge instruments?
R: Yes. Suction PIC is shown in suction header. Discharge PIC or override is shown in discharge header. These are extra items, in addition to anti-surge

Q: Our P&ID shows compressor suction PT controlling STV of a motor driven machine.
R: It is wrong. STV is throttled by upstream or suction header pressure. STV is to reduce compressor inlet pressure. So it should be sensed u/s of STV and not d/s. The configuration you have will maintain suction pressure control constant, mass inflow constant and will not work. You may have PALL at suction d/s of suction filter, both to protect against fouled strainer and too much throttling resulting in vacuum and air suck-in leading to explosion.

Q: One P&ID shows discharge PT d/s of cooler and another u/s of cooler.
R: Considering the low pressure drop of cooler relative to absolute gas pressure it should not matter. I still believe STV should be controlled by u/s vessel pressure with discharge override.

Q: Should load sharing be controlled by discharge PT and suction pressure control is by anti-surge recycle
R: No. Please read initial paras.

Q: We are asking for 20% turn down based on some of the cases and vendor is guaranteeing 70% only.
R: Below 70% you will have surge. You can’t push supplier below 70%. 20% is usual in an oil & gas field with varying flow and GOR. So go with a cooled recycle line from discharge to suction. This is a separate line with a PCV to recycle gas back to suction if you do not wish to use the

anti-surge line for this duty. This PCV will be opened by the suction PCV after it reduces the speed of the driver to minimum or on maximum throttling of surge valve. If wish you can use the anti-surge

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Vinay

Vinay Singhal

Process Engineering Manager at McDermott International Inc.

Kumar, excellent write-up. Perhaps, you can explain some things better. You mentioned that on suction throttling, you maintain the same suction volume (ACFM/ICFM) flow but at a lower suction pressure/ density; mass flow is reduced to match inflow. Head developed is reduced due to lower inlet density. Look at GPSA Figure 13-48 and 13-50. My questions are:
(1) Head is usally interpreted as independent of the density. Then what does "head eveloped is reduced to lower inlet density" means?
(2) The GPSA figure is based on net discharge pressure, and NOT "differential head". Discharge pressure can be lower due to low suction pressure; low differential pressure/head or both. What is it? Usually with a continuously dropping capacity v/s head curve (read differential head), at lower flow, differnetial head develped by the compressore should increase!

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S M

S M Kumar

Process Design Consultant

Top Contributor

Vinay:
(1) I am stumped. The consolidated response was from cut-paste-edit of several responses to different individuals. Perhaps it was from an analogy of pump curve – pressure developed is reduced due to lower inlet density. Thanks for correcting me. As I have deleted the bunch of old mails, I am unable to look into them.

(2) The GPSA figure is based controlling discharge pressure. [Vendors also give Flow Vs Discharge Pressure curve in their quotes assuming constant suction pressure, as discharge pressure as a parameter is easy to visualize]

As mentioned in the write-up, we usually tend to maintain suction pressure and have a discharge over-ride. All I want is look at “the family of curves” – in a variable speed drive such parallel head curves are produced by changing speed; here by throttling or lowering the inlet pressure. At a given V, you get the same head. Discharge pressure is lower due to lower suction pressure, when you throttle. Like centrifugal pump, compressor is a volumetric machine and the head curves are plotted against volume flow – not mass flow. Though inlet mass flow is reduced during turndown, you can maintain the suction volume flow where you want by throttling. Clear? You maintain the same ACM for 100 mass units or 80 mass units, by varying suction pressure by 20%, subject to of course not going into vacuum.

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Deepak

Deepak Goyal (AMIChemE)

Sr Engineer -Process at Petrofac

As per my understanding lower molecular weight gas will require a higher polytropic head for the same compression ratio
see equation 13.26 in GPSA

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Mojtaba

Mojtaba Habibi

Process Engineer at Wood Group

Top Contributor

Dear Mr.Kumar,

About this part of your explanation:

"Load control. Load control comes in when there is more than one compressor train. There are two approaches – (1) you run all duty trains at more or less equal load, taking care that all are equally away from surge line, that is right of the surge curve. Surge behaviour of identical trains could be different (2) Some operators prefer to operate only one train on swing load or variable load; they operate the rest of the duty trains at fixed constant load on manual control as it is supposed to increase machine life. They periodically change over the swing trains to manual and switch another train to swing load. The swing load machine maintains constant suction pressure as explained above until discharge PT/PIC overrides, if required."

Could you please explain more about the second approach? For compressor station as you mentioned everything is under control via capacity control, anti surge control, overrides and etc. Then manual operation of one train among multiple trains does not make sense to me.

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S M

S M Kumar
Process Design Consultant
Top Contributor

Assume there are 3 trains running and the load is varying from 2.4-2.7 units.
1. All on auto load sharing: All trains will keep adjusting their speeds to pick up 0.8-0.9 (2.4/3-2.7/3) loads as the gas flow changes

2. Or the operator can decide to put 2 trains on manual mode at 0.9 each. That means they will operate at some fixed speed to suit 0.9 load. Their poor third cousin will be on auto, on variable load, changing speed to pick-up 0.6 to 0.9 of the balance load, speeding down and up as decided by the prevalent gas flow.

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Mojtaba

Mojtaba Habibi
Process Engineer at Wood Group
Top Contributor

What is the benefit/gain of operating parallel trains like this procedure you described?

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Stuart

Stuart Williamson
Dynamic Simulation Consultant at CB&I

Operating parallel trains balanced in load is more efficient (all compressors operate equally distant from surge and hence at the most optimum efficiency for all three trains) and as all trains are as far from surge as possible (based on the split load) a "safer" mode of operation (assuming the control system is designed properly).
With one or more trains in manual then the overall efficiency will be less, there is more likelihood of one or more trains being in recycle when not required, and if transient operation occurs the potential for surge or cascading trips is likely to be higher.

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S M Kumar
Process Design Consultant
Top Contributor

Next query: Centrifugal compressor start-up (either initial start-up or after a pressurized shutdown of the compressor). Is it done with open or closed outlet valve. I expect the compressor start on recycle mode via anti surge line and after a while the discharge ESDV can be opened. But our compressor vendor says their compressor can be started up either with open or closed discharge valve.

My Response: I am used to (1) blow down first from settle-out to atmospheric pressure or to an intermediate pressure which the compressor motor or GT drive can handle (2) Start on total recycle with outlet valve closed until discharge pressure builds up (3) equalize pressure across outlet SDV via its 2" bypass and (4) open the main outlet valve. Let us hear from others.

Stuart: Could you add more about AVRs (Automatic Voltage Regulators) that can spike up the motor voltage to allow motor driven compressors to start from settle-out pressure. How starting from settle-out pressure handled in GT driven compressors. We are talking about 5-15 MW Oil & Gas plant centrifugal compressors.

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S M

S M Kumar
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In Part 2 of my first post, I mentioned about Dynamic Simulation program for various scenarios, usually performed by Compressor supplier. The 5 cases I know are:

1. Close inlet SDV of a compressor: To check ASV and suction PCV response; suction PALL set point; SDV closure time.
2. Close outlet SDV of a compressor: To check ASV response; discharge PAHH set point; SDV closure time.
3. Fail open of ASV of a compressor: To check compressor controls/ system response
4. Trip a compressor train: To check undesirable effects and pressure profile in u/s Separator; Determine the set points for suction PCV; Check impact on the second compressor train
5. Trip both the compressor trains: To Check response of suction PCV and set point for Inlet Separator PAHH

Please add based on your experience.

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Leila

Leila Hassanzadeh

Oil & Gas Process Engineer

Dear All,
Regarding variable speed centrifugal compressor, how much suction pressure variation is acceptable for compressor works at constant discharge pressure.

(e.g during normal operation of plant, pressure changes from 800 to 2000 psia so a compressor is required to maintain constant discharge pressure of 2000 psia, but what is the solution for operating of compressor in range of 800-2000 psia?)

regards,

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Stuart

Stuart Williamson

Dynamic Simulation Consultant at CB&I

Kumar
Dynamic simulation is not necessarily performed by the compressor vendor. In my experience the vendor usually only models a single train and looks at a limited set of cases (such as trip and start-up).
Dynamic simulation is often performed by the EPC company or external 3rd party consultants, and considers a much wider scope looking at how the compression system impacts on upstream / downstream processes / units, and parallel compression trains.
Cases that may be considered:
1) Turndown - review of the controls, performance and system at reduced throughputs
2) Reduction in feed rate to compressors, and / or reduction in discharge flow from compressors (one of these may be the same as the above), to see how the controls work when there is a capacity reduction either upstream or downstream.
3) Compression train trips to review rundown transients, settleout pressures, requirement for hot gas bypass valves, and impact on u/s and d/s units and parallel compression trains. Also checks for cascading trip events (e.g. if one train trip cascades onto others), and checks power limiting controls on parallel trains (for motor driven compressors). This can be single trains or common multiple train trips.
4) Suction and discharge blockages (typically modelled as SDV closures), looking at the anti-surge / capacity controls, trip set points, and also possibly relief rates (assuming trips & controls fail to operate adequately, etc).
5) Restart from settleout, to check driver (usually motor or industrial GT) power limitations, and confirm ASV sizing, and start-up sequence for valves and controls.
6) Start-up from a depressured condition (possibly with a different gas source - depending on where the pressurising gas is sourced from). Can check the ASV sizing and start-up characteristics, as well as the same start-up sequqnce used for the restart. This might need to be done for multiple cases if there are parallel trains (e.g. the start-up of the first may differ from the second with the first one running). Sometimes cases may include running on nitrogen (commissionning) or defrost gas (for refrigeration circuits) where the ASV sizing may differ. The nitrogen case will typically have high discharge temperatures. Sometimes start-ups at min/max ambient temperatures may be required if the process is impacted by ambient conditions (e.g. o
a recent project where min ambient temp was very low (below -40C) start-up at pressure in a refrigeration circuit was problematic.
7) Changes in feed composition looking at how the compressor peformance maps "shift", and whether the anti-surge controls can cope with the largest swings in gas MW.
8) Failure open ASV - this is oftem omitted as ivariably it usually provides limited value.
9) Checks on load sharing across parallel trains (using non-symmetrical pipework and modifying parallel compressor curves to invoke imbalances in head / flows.

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S M

S M Kumar

Process Design Consultant

Top Contributor

Stuart: I agree with you. What you have described is comprehensive and the best. Rolls Royce. What I have mentioned is the bare minimum, what is normally done in the oil & gas industry as known to me in the dark "ye be monster" part of the globe.

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Stuart Williamson

Dynamic Simulation Consultant at CB&I

Hi Kumar

Stuart If you were to do the bare minimum then you would probably just look at the trip, start-up, and possibly a turndown case. Not sure you would include the suction and discharge blockage cases, and definitely not the ASV fail open case. The cost of the additional cases is minimal in terms of the potential costs that may be incurred at site if design flaws are encountered at the commissioning / start-up phase. Not to mention the potential schedule delay that may be incurred and the potential for loss of reputation.
The technology has been proven for some time now, and is becoming far more prevalent, with most oil majors and EPCs employing this capability.

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