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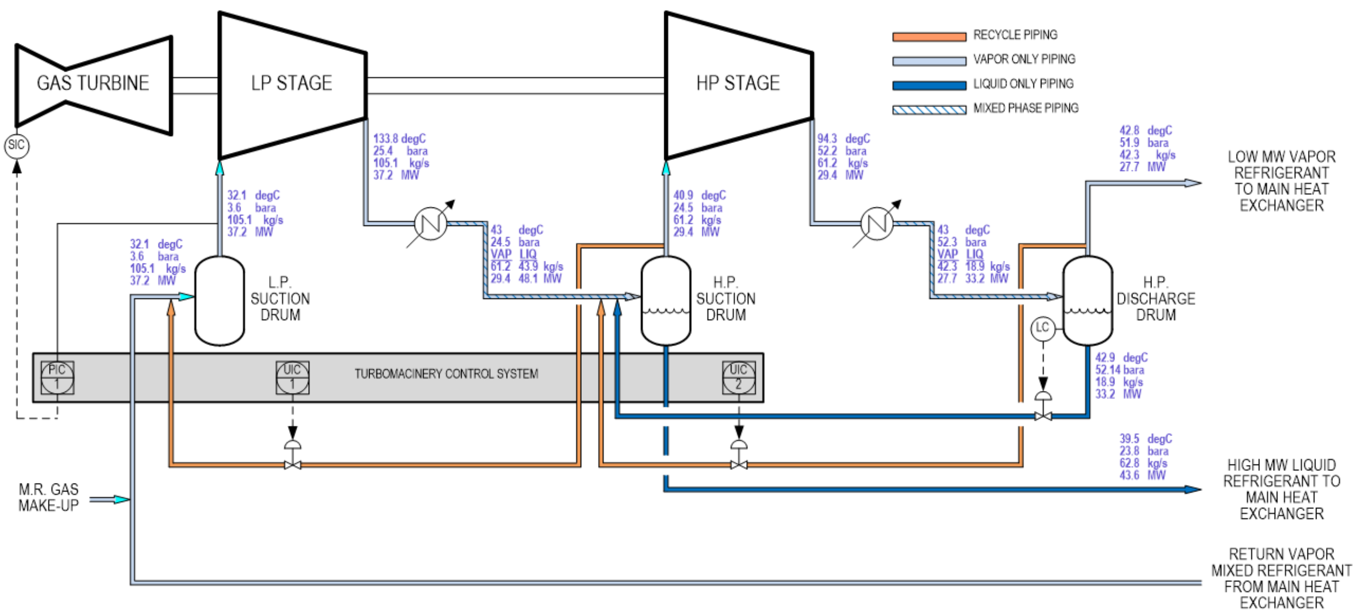
Resolving Single Mixed Refrigerant (SMR) Compressor Control Challenges



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Many small-scale LNG plants (capacities between 50,000 and 500,000 gallons per day or gpd) utilize the two-stage single mixed-refrigerant compressor (SMR) or the nitrogen (N2) expander technology. This article discusses the SMR compressor, and the compressor control system challenges associated with it's typical design.

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This article discusses the SMR compressor, and the compressor control system challenges associated with it's typical design.

A typical SMR compressor is illustrated in Figure – 1. The vast majority of such compressors are driven by a variable-speed gas turbine driver and comprise two stages of compression.

Typical SMR Compressor Layout

Mixed refrigerant vapor returns from the Main Heat Exchanger to the L.P. Suction Drum, and is compressed in the L.P. Stage of the compressor. The compressed mixed refrigerant vapor is cooled in the inter-stage cooler, which produces a mixed-phase stream, comprising the higher molecular weight liquid (approx. MW = 48.1) and a lower molecular weight vapor (approx. MW = 29.4).

This is routed to the H.P. Suction Drum, where the high molecular weight liquid is collected, and the remaining lower molecular weight gas is sent to the HP stage for further compression.

The outlet of the H.P. compression stage is cooled in the discharge after-cooler, where, again, a mixed-phase stream is produced, comprising a higher molecular weight liquid (approx. MW = 33.2) and a lower molecular weight vapor (approx. MW = 27.7), which is sent to the H.P. Discharge Drum.

Here the higher molecular weight liquid is separated from the lower molecular weight vapor, and the liquid component is sent to the H.P. Suction Drum, where it is mixed with the liquid stream condensed after the L.P stage, and producing a liquid mixture of approx. MW = 43.6, and, in turn, sent to the Main Heat Exchanger as liquid refrigerant.

The lower molecular weight vapor separated in the H.P. Discharge Drum is also sent to the Main Heat Exchanger, but as a vapor refrigerant.

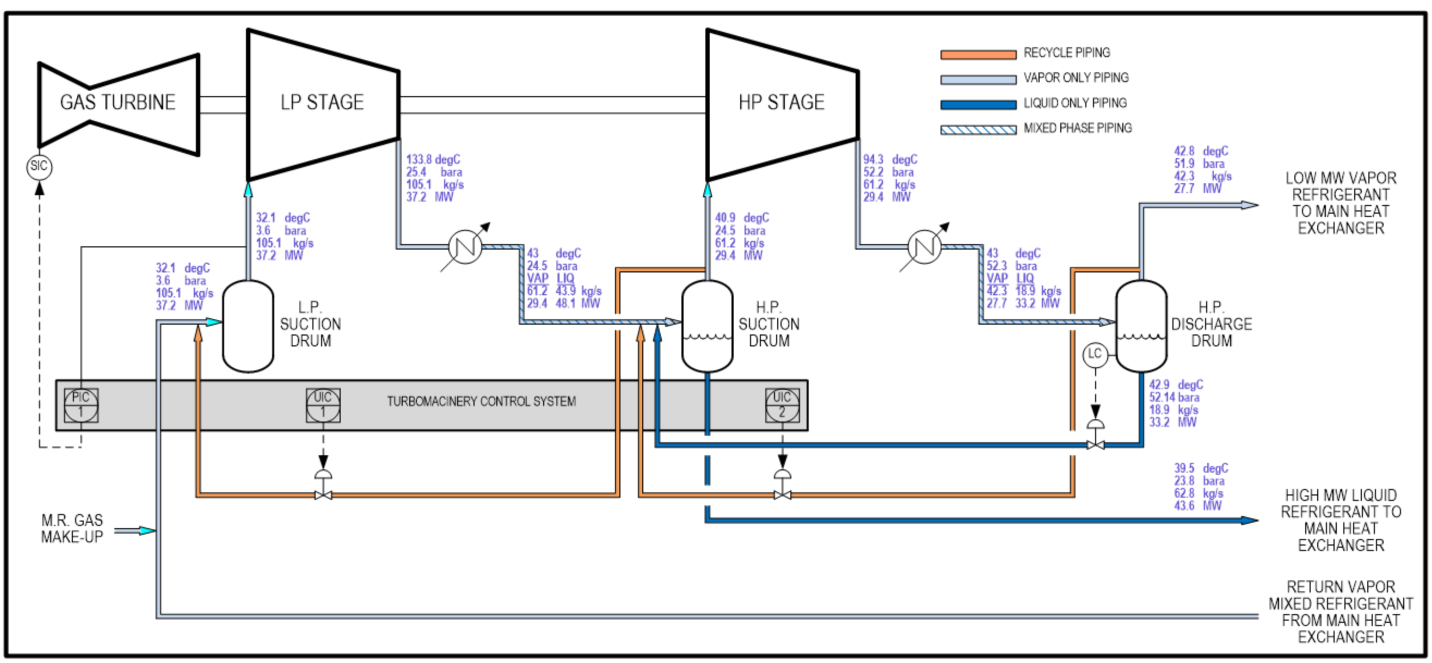

Figure 1. Typical Single Mixed-Refrigerant (SMR) Compressor Layout

Compressor Control System

A typical compressor control system consists of:

- A dedicated antisurge controller, with associated antisurge valve and recycle piping, for each compressor stage, to prevent that stage from surging when the compressor is incapable of producing sufficient head to drive the compressed vapor forwards.
- A performance controller that determines what the compressor throughput needs to be, based on comparing a suitable process variable (almost always the L.P. Stage suction pressure) to a suitable set-point value. The required throughput modulation is constrained between identified Minimum and Maximum operating speeds and sent in a cascade control arrangement as a remote set-point to the driver's governor control system.

Note: In this article, gas turbine governor is not considered a part of the compressor control system.

Control Challenges from Piping Design

A. Molecular Weight Variations:

Whenever the L.P. stage antisurge controller determines that the L.P. stage operating point has crossed its Surge Control Line, it will open the L.P. recycle valve.

With the present piping layout, this will recycle much leaner (lower molecular) weight vapor (approx. MW = 29.4) from the H.P. Suction Drum back to the L.P. Suction Drum, where the design vapor molecular weight is approx. MW = 37.2.

The introduction of significantly lower molecular weight vapor into the L.P stage will initially drive its operating point, for a given speed of operation, deeper into the surge region, whereas opening the antisurge valve is intended to have the opposite effect.

Unless the Surge Control Margin is set to an unacceptably large value, this sudden introduction of lower molecular weight gas will greatly increase the risk of several surge cycles until a new speed of operation is reached that is appropriate for the lighter vapor.

The situation is much less noticeable for the H.P. Stage, where the vapor that is recycled has a molecular weight of approx. MW = 27.7 as compared to the design operating molecular weight of the H.P. Stage of MW = 29.4. Here just a slightly wider-than-normal Surge Control Margin should prove sufficient to prevent the sudden decrease of H.P. Stage vapor molecular weight and the associated risk of surging that compressor stage.

B. Lack of Non-Return (Check) Valves:

The primary function of the antisurge controller is to protect the compressor against surge. This is achieved by lowering the resistance to compressor flow by means of opening the antisurge valve.

In order to reduce the piping and equipment volume that the antisurge valve must depressurize, a process check valve must be installed as close as possible to the downstream of the antisurge line take-off. The installation of such a check valve will define the volume that will be influenced by opening the antisurge valve to between the discharge flange of the compressor, the inlet flange of the antisurge valve and the check valve flange. This is illustrated in Figure – 2.

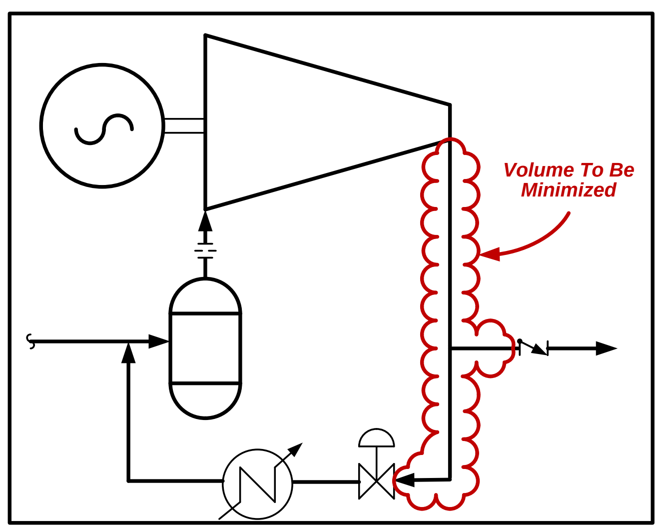

Figure 2. The Discharge Volume That Must Be Minimized for Any Compressor

In the piping layout of Figure – 1, the process piping designer did not allow for any of the required check valves. This will make the volumes that must be de-pressurized by the L.P. or H.P. antisurge valves extremely large.

This, in turn, will have a significant detrimental effect on the surge control of these two compressor stages; rendering each antisurge control too sluggish for adequate surge control and thus raising the risk of multiple surge cycles for even a moderate surge-inducing upset.

It is understandable why a non-return (check) valve was not installed downstream of the take-off of the L.P. antisurge valve: it would be located in the immediate suction of the H.P. stage, which is contrary to piping layout conventions.

On the other hand, it is not clear why the process check-valve downstream of the H.P. antisurge valve take-off was omitted.

Solutions to The Control Challenges from Piping Design:

It is possible to re-design the piping layout of the typical SMR compressor so that it is compatible with good antisurge control requirements.

For the L.P. stage, it is recommended to take-off the L.P. recycle line close after the L.P. discharge flange, and before the interstage cooler. This will ensure that the recycle gas that is introduced into the L.P. stage will have the same composition, and hence molecular weight as the L.P.'s design conditions.

Obviously this recycle gas will be heated as it is compressed in the L.P. stage, and must be cooled to the design inlet temperature. The best way to do this is to add a recycle cooler, as shown in Figure – 3.

It is also recommended to install a non-return (check) valve immediately after the proposed recycle line take-off.

Concerning the H.P. stage recycle, it is recommended that it begins also close to the H.P. stage discharge flange, and before the H.P. after-cooler, and it can terminate between the L.P. discharge non-return (check) valve and the interstage cooler.

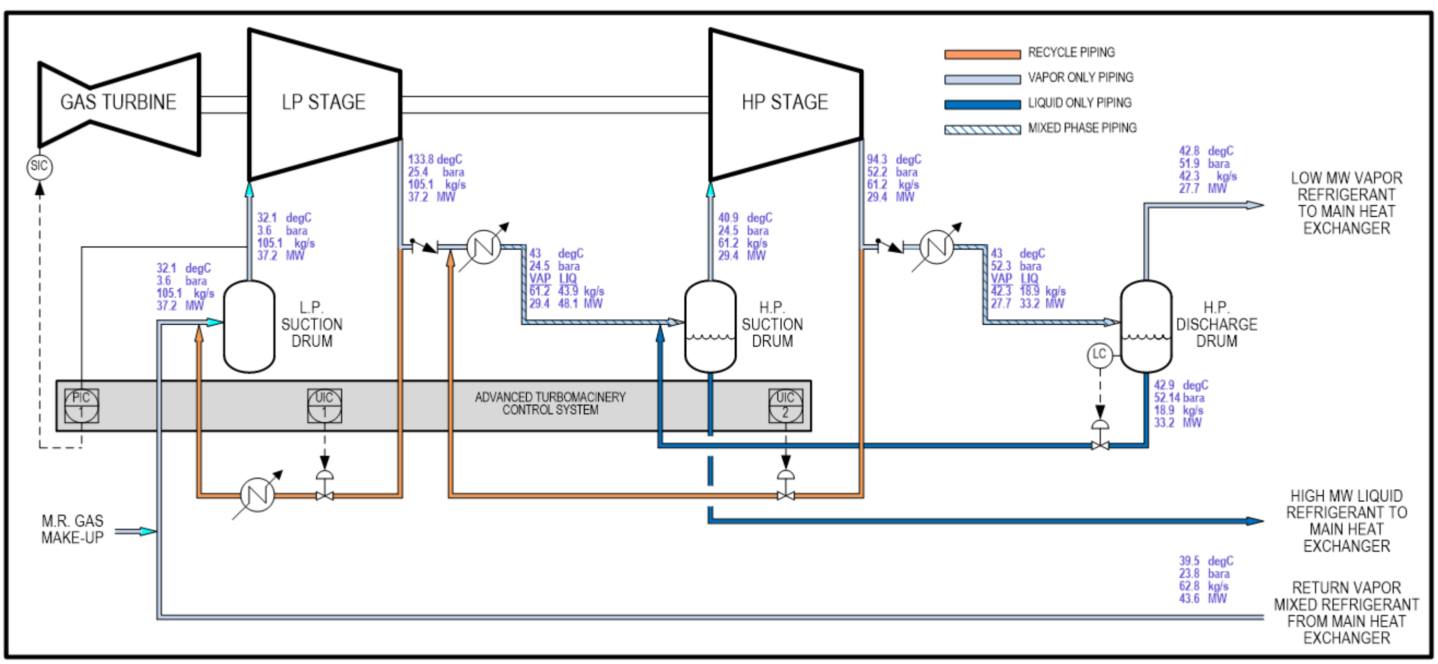

Figure 3. Recommended Single Mixed-Refrigerant (SMR) Compressor

Again, a non-return (check) valve should be installed immediately after the H.P. recycle line take-off.

Control Challenges from Performance Curves Shape:

The performance curves, as generated by the compressor manufacturer, displayed a significant change in slope for the Surge Limit Line, as shown in Figure – 4.

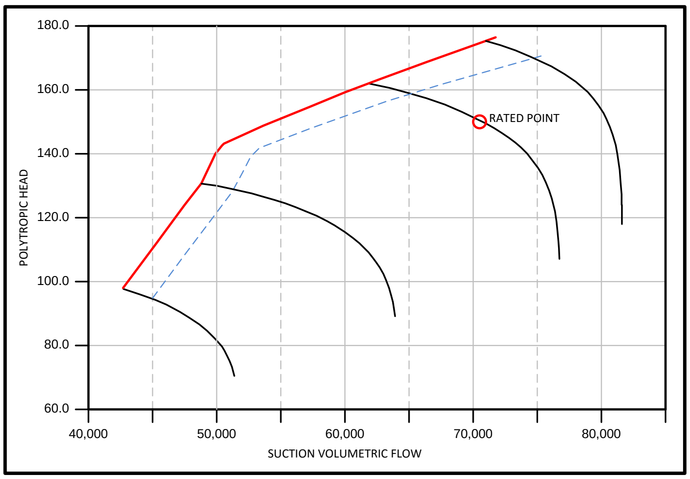

Figure 4. L.P. Stage Performance Curve Shape as Designed

This introduces another challenge in tuning the compressor control system.

Normally when there is a surge inducing upset to the compressor stage, the operating point makes a trajectory along the curve from points 1 to 2 as depicted in Figure – 5.

For a compressor that is setup to control its suction pressure, a surge-inducing upset will cause the compressor to operate at a higher pressure ratio or head, which in turn diminishes the flow through the compressor. This will cause the suction pressure control to see the value of the suction pressure rising above the designated set-point, and hence the modulating action of the performance controller will be to lower the remote speed set point of the gas turbine driver.

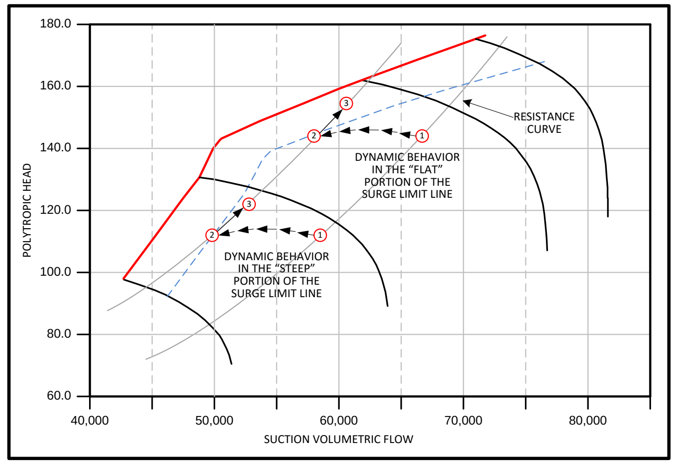

Figure 5. L.P. Control System Tuning Depends on the Region of the Performance Curves

When the surge Control Line is reached (at point 2 in the Figure – 5), the opening of the antisurge valve will cause the operating point to move in the trajectory 2 – 3 in the illustration of Figure – 5.

Consider a properly tuned combination of performance and antisurge controllers so that opening the antisurge valve causes the trajectory of the operating point to follow the shape illustrated in the lower portion of Figure – 5.

When the same tuning is applied to a surge-inducing upset that occurs above the point where the Surge Limit Line makes a slope change, then there is the risk that opening the antisurge valve will cause the performance controller to move the operating point closer to surge, rather than further away from it. This is also illustrated in Figure – 5.

If the antisurge and performance controllers were to be tuned for a good response in the performance control region above the Surge Limit Line change-of-slope point, then the same tuning, applied below the Surge Limit Line change of slope point may result in an overly aggressive opening of the antisurge valve and an overly slow performance control action; when applied to the region below the Surge Limit Line change of slope.

Compare the dynamic behavior of the compressor control system for a given upset – illustrated in Figure - 5, above, with a comparable upset and the same tuning for the H.P stage, where the change in slop of the Surge Limit Line is much less pronounced, as illustrated in Figure – 6.

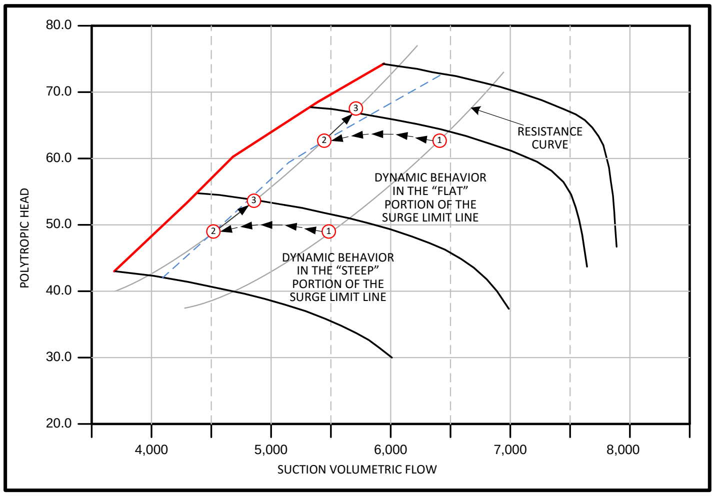

Figure 6. H.P. Control System Dynamic Behavior Example

As a general recommendation, it is advisable for the compressor manufacturer to select the wheels (rotors) for each stage such that any significant change in the slope of the Surge Limit Line is avoided.

About the Author:

Medhat Zaghloul is CCC's Regional Technology Manager for the Europe, Middle East and Africa Regions with Compressor Controls Corporation (CCC), based in the Abu Dhabi Office. Medhat joined CCC in 1993 and has over 38 years of experience in the oil and gas industry with 15 years specific to the instrumentation and controls for the petrochemical industry. He is responsible for the development of technical solutions and control applications and providing technical guidance and support. Mr. Zaghloul holds a B.Sc. in Electrical Engineering from the Cairo Institute of Technology in Egypt (now Helwan University).