THE DEVIL IS IN THE DETAILS

Alan Wong, Compressor Controls Corp., Singapore, discusses the results of an investigation into an improperly designed, engineered and commissioned carbon dioxide compressor's piping, instrument and control system in a fertilizer plant.

Compressors are widely utilised in fertilizer plants worldwide. Their associated piping and instrumentation design and control systems play a major role in determining the safety, stability and efficiency of the fertilizer manufacturing process. This article examines the compressor's piping and instrumentation design, its control system based on a fertilizer plant's carbon dioxide (CO_2) compressor, and how a compressor surge test can be performed to reduce compressor energy consumption.

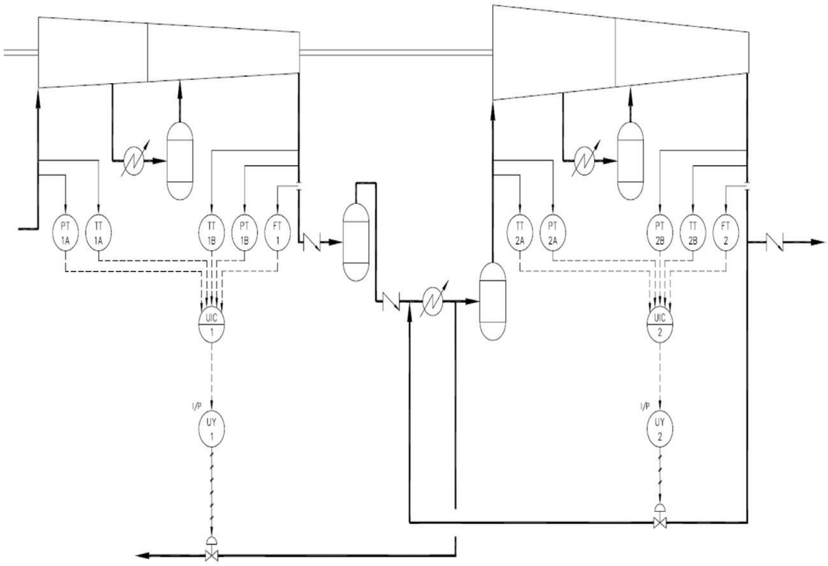

Figure 1. Simplified CO_2 compressor piping and instrumentation diagram.

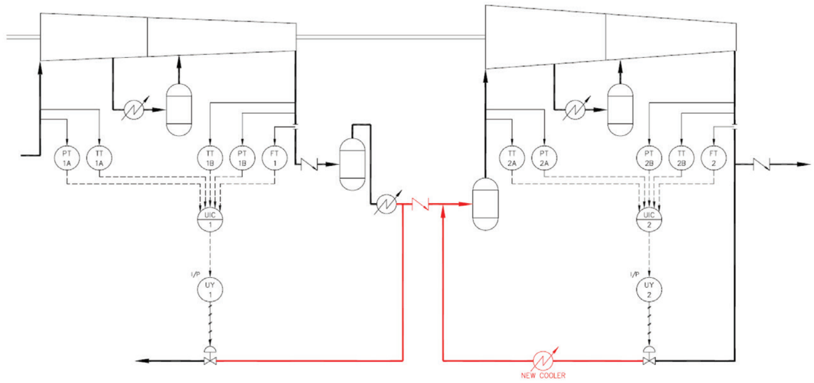

Figure 2. Preferred CO_2 compressor piping and instrumentation diagram.

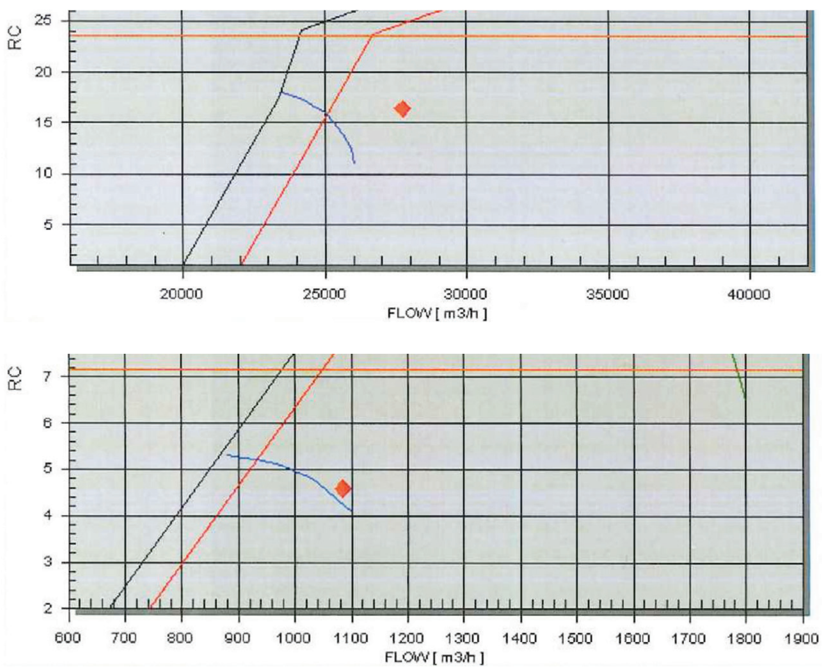

Figure 3. LP casing operating point (top), and HP casing operating point (bottom).

Compressor piping and instrumentation design

Figure 1 shows a diagram of the piping and instrumentation of a steam turbine-driven CO_2 compressor in a fertilizer plant. The compressor has two casings, namely, the low pressure (LP) casing housing the compressor's stages 1 and 2, and the high pressure (HP) casing housing the compressor's stages 3 and 4. There are two recycle loops: one starts from stage 2 discharge back to stage 1 suction, and the other starts from stage 4 discharge back to stage 3 suction. These two recycle loops criss-cross each other to share the inter-casing cooler. Criss-crossing the two recycle loops prevents the installation of a check valve immediately downstream of the LP recycle loop takeoff point that would isolate the excessive piping and instrumentation volume – an essential item for effective and efficient antisurge control. The result is an inordinate volume that the first casing recycle valve needs to handle. Consequently, the LP casing antisurge controller needs to have a wider surge control margin to counter the excessive piping and instrumentation volume, thus heightening the chances of the LP casing recycle valve opening and therefore wasting energy. This limits its effectiveness and lowers the compressor's operation efficiency.

The recommended compressor piping design is shown in Figure 2, which has the two recycle loops separated by a check valve in red rather than criss-crossed. This check valve cuts off the excessive piping and instrumentation volume for the LP casing antisurge controller, creating a narrower and more energy-efficient antisurge control margin. This reduces the chances of the recycle valve opening, and improves its effectiveness and the compressor's operation efficiency.

It should be noted that a new cooler (Figure 2, in red) may or may not be needed to cool off the recycled gas of the HP casing recycle loop, depending on how much CO_2 gas cooling is achieved from its expansion during recycling.

Incorrect compressor piping and instrumentation design is very difficult, if not almost impossible, to correct once the compressor has been installed and the piping has been built. Therefore, it is of utmost importance that the compressor piping and instrumentation design be thoroughly reviewed as early as possible in the project design phase to avoid such errors.

Oversized recycle valves

The company examined the two recycle valves and confirmed that they were oversized. These oversized valves caused loss of valve control resolution, excessive recycling and destabilising of the process. For a compressor to operate stably, reliably and efficiently, recycle valves must be sized correctly (neither undersized nor oversized), such that opening one yields safety (countering the potential surge or bringing the compressor out of surge), stability (reducing excessive discharge pressure or raising up low suction pressure) and efficiency (doing so by opening just enough to counter the process disturbance to the compressor and process operation).

Oversized recycle valves cannot achieve the aforementioned qualities but instead trigger a large amount of flow that pushes the other casing into surge, destabilising the already-disturbed process by recycling too much due to its oversized nature, severely reducing the vital supply of CO_2 to the process – which heightens the risk of tripping the process – and wasting energy by excessive recycling.

Incorrectly sized recycle valves are difficult and costly to rectify once they have been purchased. It is therefore imperative that these valves be sized correctly to avoid these issues during the detailed engineering phase. The recycle valve sizing, which is usually calculated by compressor original equipment manufacturers (OEMs), should be verified by qualified engineers from compressor controls consultants.

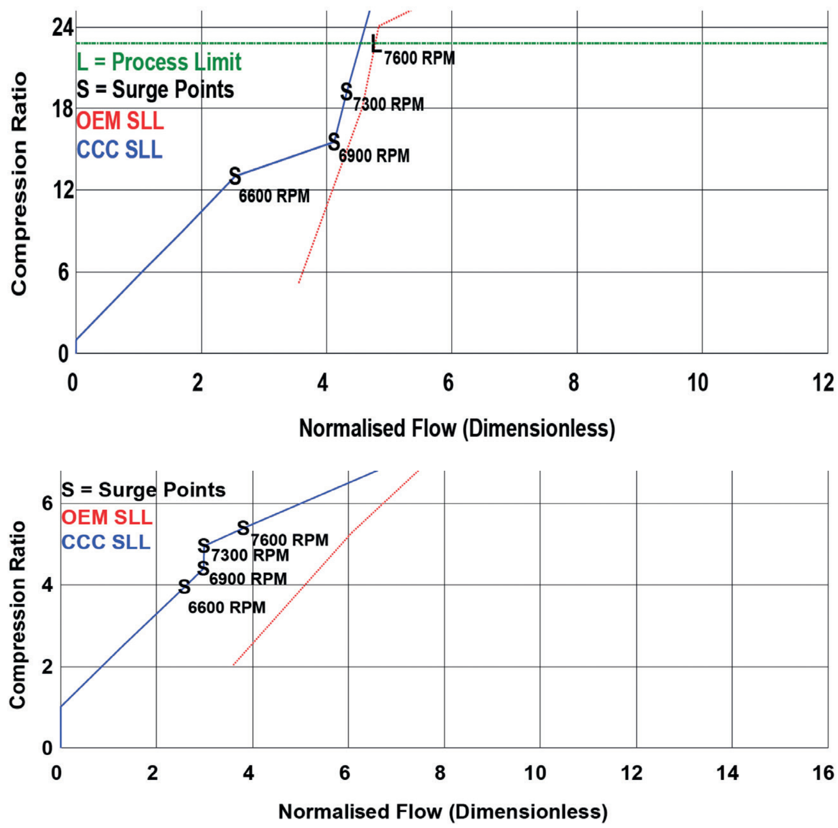

Figure 4. LP casing actual surge line vs OEM surge line (top), and HP casing actual surge line vs OEM surge line (bottom).

Inefficient compressor operation

It is often assumed that the upfront cost of building a new fertilizer plant (which includes multiple new compressors) is the biggest investment. However, a 20 000 hp (~15 MW) compressor's 30-year lifespan energy cost is approximately US$180 million (~97% of the total cost), whereas its initial cost is only an estimated US$1.5 million (~0.8%) and the cost of maintenance is approximately US$4.5 million (~2.4%).[1] This means the true focus should be on the compressor's energy cost. The extent to which its energy cost can be minimised is directly related to how well its piping, instrumentation and control system are designed.

In the competitive market environment of today's fertilizer industry, operating compressors efficiently in the fertilizer plant is not a choice but rather a must. Often, however, incorrect piping and instrumentation design and excessive surge control margin in the compressor control system – due to lack of advance controls technologies – means recycle valve opening, constant recycling of compressed gas and the consumption of more energy than is necessary.

Figure 3 shows the LP casing and HP casing operating points of the CO_2 compressor located far away from its surge limit lines but CO_2 gas was recycled from approximately 155 bar back to approximately 1 bar.

The CO_2 compressor operated with too conservative surge control margins. When the plant's load was reduced due to operational reasons, the compressor tended to operate more to the left side of the compressor map, edging closer to the compressor surge zone (left side of the black surge limit lines). When the operating point of one of the casings hit the surge control line (SCL), the recycle valve of that casing opened. Due to the interactive nature of one antisurge control on the other, the recycle valve of the other casing eventually opened. The combined effect was that CO_2 gas was recycled from approximately 155 bar final compressor discharge pressure down to approximately 1 bar, a substantial pressure drop that wasted a lot of energy. This was due to the compressor control system's lack of advanced antisurge control technologies, which if installed allows more reasonable surge control margins. In the absence of these technologies, the system was left with overly conservative surge control margins.

In addition, it is critical for a compressor control system that has multiple recycle loops to coordinate the antisurge control responses to avoid undesirable control interactions. Due to the lack of control coordination between the antisurge controls, hunting occurred between the two recycle valves, further destabilising the already disturbed process and compressor, and prompting operators to vent off CO_2 at the compressor's discharge and trip the compressor, losing both the production and inventory. To reduce the likelihood of such an occurrence, the user purposefully ran excessive CO_2 capacity through the compressor and recycled the excessive CO_2 such that the compressor had excessively large margins against process disturbance and operators did not need to trip the compressor during process disturbance. This resulted in operating points well to the right of the SCLs, which further exacerbated the issue of inefficient compressor operation.

Compressor surge test

The compressor OEM did not conduct a surge test under normal site operating conditions during the compressor's inaugural commissioning. The lack of surge tests under normal site operating conditions may prevent the antisurge control system from using the actual surge lines, which may be to the left of the surge lines indicated on the compressor maps. This increases the chances of the recycle valve opening and reducing the compressor's operating efficiency.

The company performed surge tests on this compressor at various speeds to verify the surge lines and found that the surge lines were well to the left of the OEM surge lines and also far too consecutive. Figure 4 shows the surge test results on an antisurge control coordinate system of compression ratio vs normalised dimensionless flow, where the red lines were the original OEM surge lines and the blue lines were the actual surge lines found during the surge tests of the LP casing and HP casing respectively.

By using the actual surge lines and with proper coordinated antisurge controls for both casing, the recycle valves were able to close fully, which halted the recycling and reduced the compressor's energy consumption.

Conclusion

As the saying goes, the devil is in the details. It may not be obvious that improper compressor piping and instrumentation design, incorrectly sized recycle valves, or compressor control systems without advanced antisurge control technologies can cause considerable challenges to compressor operations. However, these little details are often the root causes of a compressor's unsafe, unstable or inefficient operation.

Consultation services during the FEED stage (or as early as possible) of new construction projects can identify these issues and ensure that the piping and instrumentation design and compressor control systems are sound. Compressor surge test services for existing plants can also verify the exact surge line locations for potential compressor operation optimisation services. WF

Reference

1. DUGGAN, B., and LOCKE, S., 'Experiences in Analysis and Monitoring Compressor Performance,' paper presented at 24th Turbomachinery Symposium, 26 – 28 September 1995, Houston, Texas, US.