Evaluating Compressor Reliability – An Operator's Perspective of Assessing Vibration Risk Across the Operating Envelope

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1. ABSTRACT

Dominion Transmission, Inc., like other operators of gas compressors, is focused on identifying and mitigating reliability risks associated with their assets. This is especially challenging for reciprocating compressors which must operate across a range of suction and discharge pressures, unloading schemes, and flow conditions. Often 50 to 300 conditions are assessed to properly understand pulsation, vibration, and performance issues. The resulting data can be overwhelming and difficult to interpret.

This presentation will provide a Customer's perspective to assessing reliability risks. Using results from recent Dominion compressor projects, the authors will illustrate how vibration and performance risks are often hidden and lurking in the background, but will become a reliability problem at some point in the future. This case study will also offer ideas for improving the assessment process.

2. INTRODUCTION

Operating flexibility is one of the benefits of single- and multi-stage reciprocating gas compressors. With increased operating flexibility comes increased risk of reliability problems.

Some of this reliability risk can be reduced at the planning stage, during compressor selection. Other reliability risk can only be reduced during the design process, by external consultants.

This paper explores ways to reduce reliability risks through various analyses and procedures.

3. RISKS

Reliability is a measure of how well equipment can perform its intended function. Risks to compressor reliability can be broken down into three different categories:

1. Short term failure risks are risks that cause failure of a critical component in a relatively short time. They can be mitigated by design studies and/or field start up checks.
2. Medium term failure risks are risks that can turn into short term failure risks if regular maintenance is not conduced, design studies are not done, or the compressor is operated at undesirable operating conditions.
3. Performance risks are risks to compressor performance like power and capacity. They are unlikely to turn into failure risk, but may be costly nonetheless.

The trade off for reducing reliability risks can be increased cost (fixed and/or ongoing) and/or reduced performance. Identifying reliability risk early in the planning and design process reduces the severity of the trade off in cost and performance. The overall life-cycle costs must be considered to find a balance between cost, reliability, and performance.

The failure of a critical component is the greatest risk to life and property in a compressor installation. Table 1 summarizes the risks associated with compressor reliability.

Calculating some performance risk requires very little information. These risks are classified in Table 1 as “Simple”. For example, calculating rod load, rod reversal, and driver overload only requires the compressor geometry and the gas properties at the compressor cylinder flange. Some performance risks require significant information about the system, including piping layout and pulsation bottle design. These risks are classified in Table 1 as “Complex”. In some cases, “simple” performance risks that were initially calculated may change as the design of the compressor package evolves. For example, the actual pressure at the compressor cylinder flange depends on the actual pressure drop from the fence (firegate) to the compressor, which can be significantly different than the pressure drop assumed at the planning stage during compressor sizing.

Some components will fail very quickly when there are problems. If a compressor crankshaft or small bore piping operates at resonance and has stresses over its endurance limit, it will fail within hours. Other components will fail gradually or become a reoccurring maintenance problem. Piping and vessel vibration may cause pipe supports and wedge supports to loosen, which may eventually lead to failure if regular maintenance is not performed. Finally, some risks are simply that design requirements, like compressor capacity, will not be met.

All reliability risks vary across the operating range of the compressor. Altering the operating conditions is a mitigation strategy that can be applied to any of the compressor reliability risks, shown in Table 1. For example, avoiding unloading on certain cylinders can mitigate torsional vibration problems; blocking out speed ranges can mitigate high vibrations on piping and vessels due to resonance; and avoiding certain operating conditions can reduce rod load and non-reversal problems. Of course, altering the operating conditions may cause the compressor to fail to meet the design requirements.

Table 1. Risks to compressor reliability

	Component	Risk description	Cause(s) of risk	Consequence(s) of risk	Mitigation of risk	
Short term failure risk	Compressor piston assembly	High rod loads cause stress above yield limit	•Compressor operating condition	•Piston assembly failure	Original equipment manufacturer (OEM) or third-party performance software	Simple
	Crosshead pin	Pin and bushing lubrication stops	•Rod non-reversal	•Pin and bushing failure	OEM or third-party performance software	
	Drive train	High torsional vibrations cause stress above endurance limit	•Torsional resonance •High dynamic torques	•Crankshaft failure	Torsional vibration analysis	Complex
	Small bore piping (SBP) attached to main piping or vessel	High vibrations cause stress above endurance limit	•Mechanical resonance •High vibration of main piping or vessel	•Cracks •Gas release	SBP design analysis and/or field SBP survey	
	Compressor frame and cylinder	High vibrations cause failure of compressor components	•Mechanical resonance •High dynamic forces[1]	•Compressor failure	Foundation study and/or dynamic skid analysis	
	Piping, vessels, and equipment	High vibrations cause stress above endurance limit	•Mechanical resonance •High dynamic forces[1]	•Cracks in piping and vessels •Gas release •Equipment failure	Pulsation/vibration study	
Medium term failure risks	Valve	Low volumetric efficiency causes valve damage and high gas temperature	•Compressor operating condition	•Valve failure •Alarm shutdown due to high discharge temperature	OEM or third-party performance software	Simple
	Valve	High pulsations at valve cause valve damage	•High pulsations	•Valve failure	Pulsation/vibration study	Complex
	Compressor, piping, vessels, and equipment	High vibrations cause vibratory loosening of bolted components and/or failure of non-critical components	•Mechanical resonance •High dynamic forces[1]	•More frequent maintenance and replacement of components	Pulsation/vibration study	
Performance risks	Driver	Overload	• Fence-to-fence pressure drop higher than assumed	• Compressor capacity unable to meet requirements	Pulsation/vibration study	Complex
	Valve	High pulsations at valve causes distortion of Pressure-Volume curve	•High pulsations	•Change in compressor capacity and/or power	Pulsation/vibration study	

Notes:
1. Typical dynamic forces include compressor forces and moments, cylinder gas forces (cylinder stretching forces), crosshead guide forces, and pulsation-induced shaking forces.

4. DESIGN PROCESS

Trying to anticipate these risks to compressor reliability can be challenging at the planning and design stages of a project. The two main reasons for this are:

1. Groups involved during the planning and design stages may have different priorities, and
2. Parties who can help identify reliability risks (e.g., pulsation and vibration consultants) may not get involved until later in the design process.

Consider the design process (Figure 1) for an injection withdrawal unit, which will be referred to as Compressor "Q". This unit will be looked at in more detail in the case study in Section 5. For this project, the design process steps included:

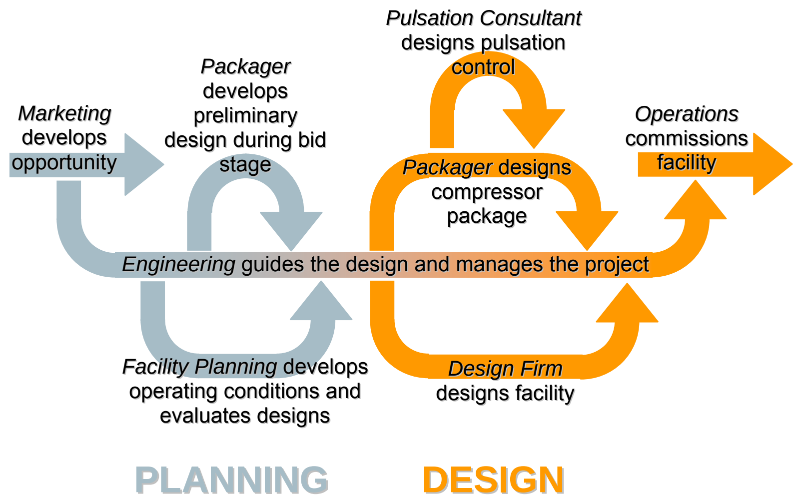

Figure 1. Example of project flow for a new facility

- Marketing discussed pressures and flow rates with customer and Gas Storage engineers.
- Facility planning took those pressures and flow rates, created a pipeline simulation model, and determined what new facilities were required, including pipelines and compression.
- Engineering developed a cost analysis of the project, and included bids from compressor packagers and design firms.
- Compressor packagers sized compressor and initially laid out package.
- Facility planning evaluated performance to understand reliability over operating range.
- Contracts were awarded and the packager and design firm began with detailed design.
- At this stage, a pulsation consultant was sub-contracted by the packager to evaluate the pulsation control and make recommendations.

In this particular case, the packager only evaluated five (5) compressor operating conditions, two (2) of which were analyzed in detail during the pulsation/vibration study conducted by the pulsation consultant. The important question to answer is: Are these two conditions enough to adequately identify the "complex" reliability risk to Compressor "Q"?

5. CASE STUDY – COMPRESSOR "Q"

Dominion Transmission required a new injection withdrawal unit (Compressor "Q"). Typical of injection withdrawal units, it can run in one-stage or two-stage operation. For the purpose of the case study, only the two-stage operation will be discussed. Compressor "Q" has the following properties:

- Ariel JGZ/4 two-stage compressor (Figure 2) driven by a Caterpillar G3608LE engine over a speed range of 750 – 1000 RPM.
- Suction pressure varies from 350 – 950 psig and discharge pressure varies from 1300 – 3020 psig.
- Flows range from 13 – 81 mmscfd.
- Suction temperatures range from 45 – 81 deg F.

- One gas composition with a specific gravity of 0.59.
- Operates using a Programmable Logic Controller (PLC) to control compressor load steps which are a mixture of head-end and crank-end pockets, and valve unloaders.

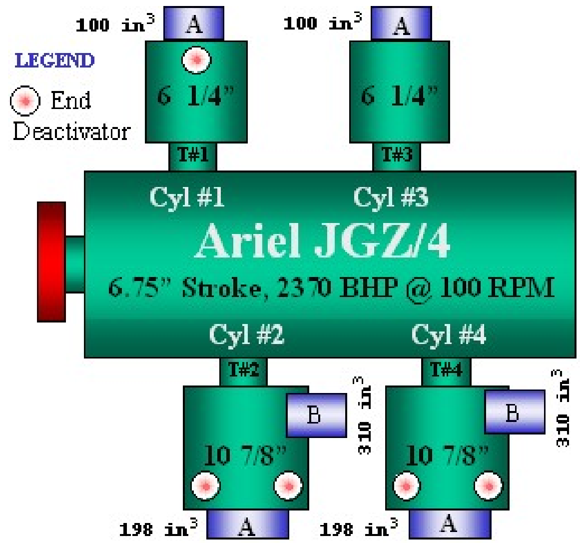

Figure 2. Compressor "Q" configuration

Third party software was used to evaluate hundreds of operating conditions for "simple" reliability risks of rod load, reversal, etc. However, only a few operating conditions were passed on to the packager and, ultimately, the pulsation consultant. In fact, the pulsation consultant only considered two-stage operation and did not consider one-stage operation.

There are several reasons for not passing on comprehensive operating conditions to the packager and pulsation consultant:

- The packager typically only has to meet a few guarantee points and is not concerned about other operating conditions.
- Owners are not aware of the importance of analyzing additional operating conditions.
- The actual compressor operation and load steps may not have been finalized by the owner when the packager was contracted, and therefore the packager was given approximate operating conditions. In some cases, the pulsation study may be completed before the compressor operation is finalized.

6. RELIABLE OPERATING MAP

At the planning stage, a reciprocating compressor is chosen to meet flow and pressure requirements. Once these factors are met, the reliability risks that prevent the compressor from operating over the entire suction and discharge pressure range are evaluated.

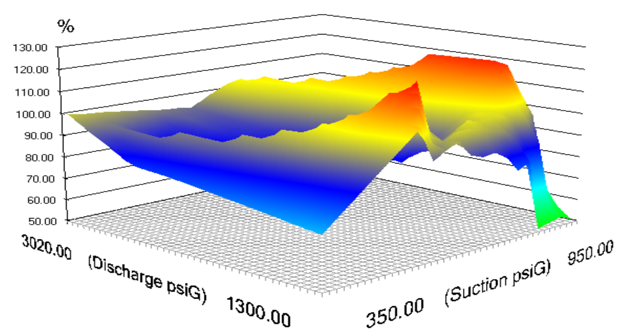

Figure 3. Rod load as a percent of rated rod load for Compressor "Q"

For Compressor "Q", third-party software was used to generate the reliable operating maps due to various "simple" risks like high rod load (Figure 3), rod reversal, and driver overload.

Creating a complete reliable operating map involves overlapping the factors outlined in Table 1 on the operating range of the compressor. Figure 4 shows an example of how to create a reliable operating map using some of these factors. The green area is the desired operating range. The factors in red are "simple" reliability risks that can be calculated using OEM or third party performance software. The factor in yellow is a "complex" reliability risk that can only be calculated after a pulsation/vibration study is completed.

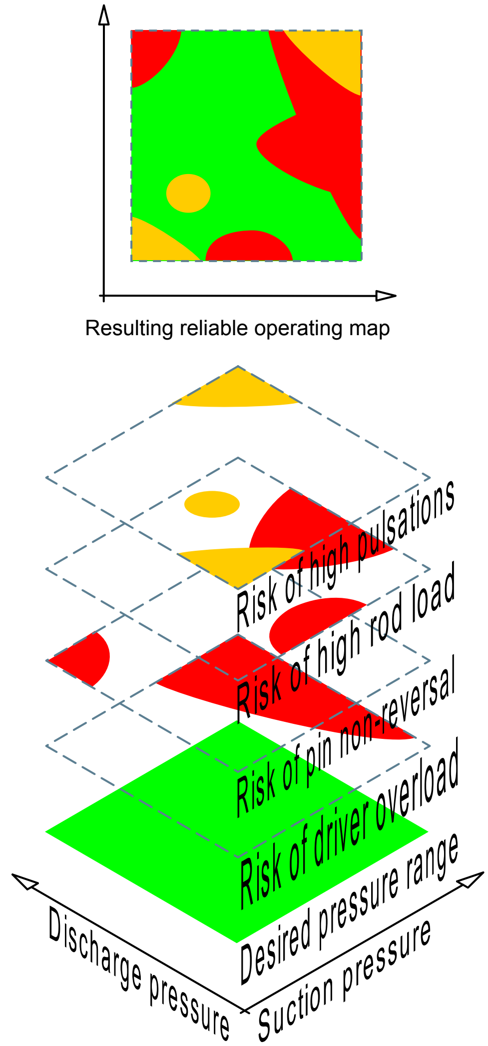

Figure 4. Reliable operating map

The impact of "complex" reliability risks depends on the progress of the compressor design. If the detailed design is complete, then modifying operating conditions may have a significant impact on schedule, cost, and performance. At the planning stage, the impact may be less. For example, crank end volume pockets, which tend to result in lower pulsation levels, could be used instead of head end valve unloaders. Other options that could be used include larger pulsation bottles and/or secondary volumes to reduce pulsation levels.

7. PULSATIONS

As shown in Table 1, pulsations can cause three different risks to compressor reliability. First, they can create shaking forces in piping and vessels which can lead to maintenance problems and even fatigue failures. Second, they can affect valve performance which can affect valve life and compressor performance. Third, they can increase the pressure drop through a piping system, which can affect compressor performance.

Pulsation amplitudes are greatly affected by the way a compressor is operated. The main three factors that affect the amplitude of the pulsations created by a reciprocating compressor are:
1. Loading (single-acting or double-acting, and clearance volumes)
2. Suction pressure
3. Compression ratio

Figure 5 shows the relative amplitudes of pulsations at different orders of compressor runspeed for different operation of Compressor "Q". These include fully loaded (shown in green), crank end fixed clearance pocket open (CEPO) (shown in yellow), and head end valves unloaded (HEVU) (shown in red). Several different suction pressures (PS, psia), pressure ratios (PR) and cylinder capacities (Q, mmscfd) are given, for each of the unloading configurations.

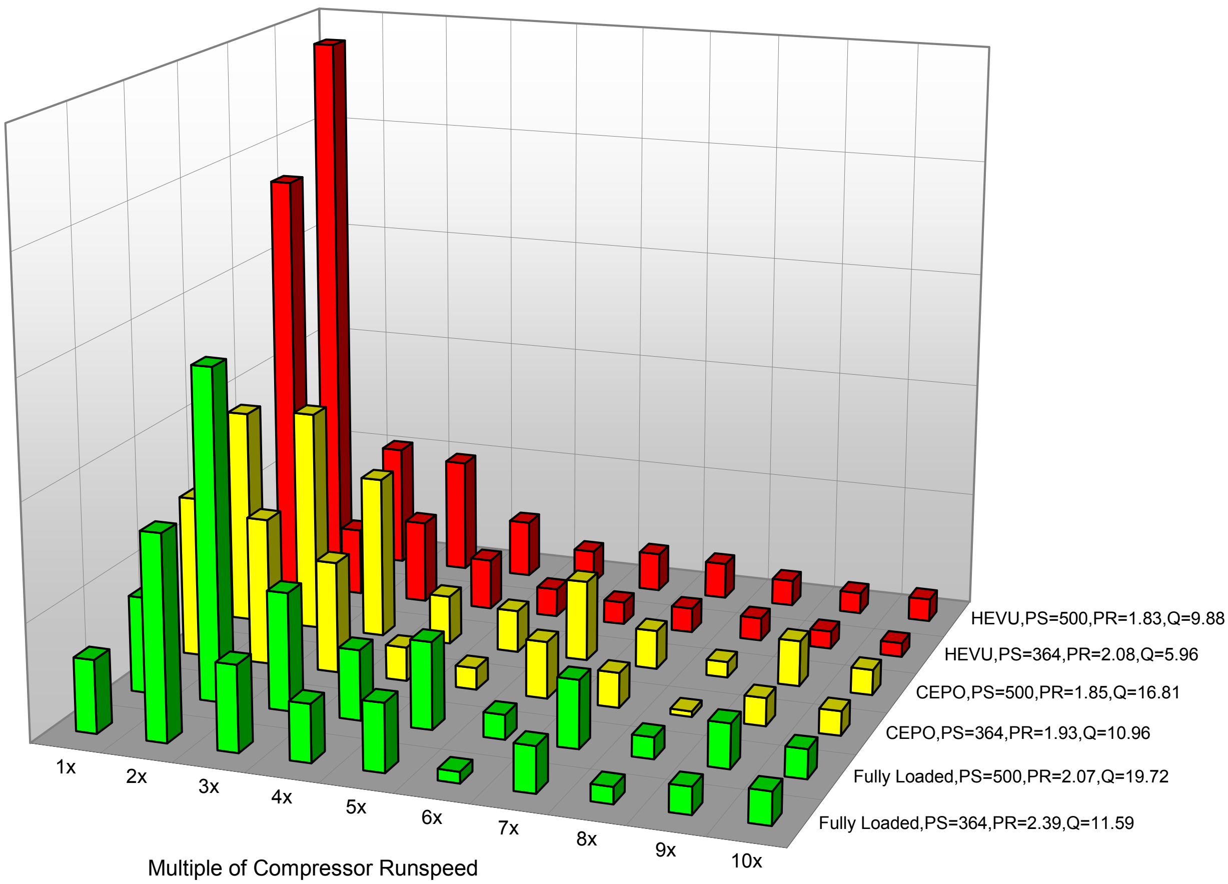

Figure 5. Relative pulsation amplitude for different operation of Compressor "Q"

What is clear from Figure 5 is that operating single-acting vs. double-acting has the largest affect on pulsation levels. Increasing clearance volume also has a large affect on pulsation levels. The reason the 1x pulsations increase slightly when the cylinder clearance is increased, and significantly when the cylinder valves are unloaded requires some understanding of compressor operation.

The majority of pulsations created by a double-acting reciprocating compressor are at twice compressor runspeed (also described as 2x compressor runspeed) because the valves on the suction (or discharge) side open *twice* per crankshaft rotation: first the head-end valves then the crank-end valves. When a compressor cylinder is single-acting, the valves only open once per rotation and therefore the majority of pulsations are at 1x compressor runspeed. As a compressor cylinder head-end pocket is opened, the head end valve opens for a shorter time (as the volumetric efficiency is reduced) and the pulsations from the head-end side tend to shrink. This has the effect of decreasing the pulsations at 2x compressor runspeed and increasing the pulsations at 1x compressor runspeed, but not as much as if the cylinder were single-acting.

Increasing the suction pressure also has a large affect on pulsation levels. Compression ratio will also have an inverse affect on pulsation levels (i.e., the lower the compressor ratio, the higher the pulsation levels), but not as significantly as the other factors. Gas temperature and specific gravity can also affect pulsation levels, but they tend vary over a smaller range than pressure and unloading and therefore have less of an effect.

Higher pulsation levels, especially ones at lower multiples of compressor runspeed, require larger and more complicated pulsation control devices (which increase capital costs) or pulsation control devices which introduce significant pressure drop (which reduces performance). Typically, low pass filters (also called volume-choke-volume filters, e.g., bottles with baffles and choke tubes) are required when pulsation levels are high and at lower multiples of compressor runspeed. It is important to note that while the compressor operating speed range does not affect pulsation levels, it greatly affects how effective low pass filters are in controlling pulsations.

7.1. Shaking forces

Short term failure risks are not caused by pulsations themselves, but rather by the shaking forces that they create. Shaking forces are created because time-varying pulsations act on changes in area and direction in the piping system.

Shaking Forces = Pulsations x Area

Vibrations are caused by the interaction between dynamic forces, including pulsation-induced shaking forces, and the dynamic flexibility of the piping, vessels, and structure. The “dynamic” in dynamic flexibility only means that structures are more flexible at certain speeds, which is called the structure’s *mechanical natural frequency* or *MNF*. Vibrations can be high when the dynamic forces are high. But vibrations can also be high when the dynamic forces are acceptable but the flexibility is high, which occurs at a structure’s MNF. This latter cause of high vibrations is called *resonance*.

Vibrations = Dynamic Forces x Dynamic Flexibility

These formulas point to two practical strategies to reducing the risk of high vibrations due to shaking forces: 1) reducing pulsations, and 2) decreasing dynamic flexibility.

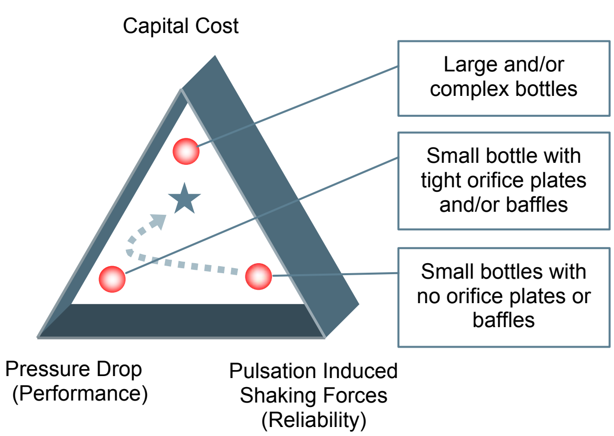

Figure 6. Balancing pulsation control

Controlling pulsations involves balancing compressor performance, reliability, and capital costs (Figure 6). Undersized pulsation bottles or insufficient pulsation control design can lead to high pulsations and shaking forces, which increases the reliability risk. Increasing the pulsation bottle size will reduce pulsations and therefore reduce the reliability risk. However, this will tend to lower the bottle mechanical natural frequency (increasing the dynamic flexibility), which will again start to raise the reliability risk. Adding orifice plates is a simple way to control pulsations, but it has a large impact on pressure drop, which affects performance (capacity and power). A balance between cost, performance, and reliability can usually be achieved with a few orifice plates and a medium size bottle with internal elements like baffles and/or choke tubes.

7.2. Valve performance

Pulsations can affect valves by causing them to slam closed, hold open, or chatter. These affect the life of the valve and the performance of the compressor, the latter by altering the P-V curve. Typically, restrictive orifice plates located at the compressor cylinder flange will reduce pulsations in the gas passage, and near the valve, to acceptable levels.

The affect these pulsations have on performance tends to be minimal, and can even increase the performance of the compressor by reducing the required power and/or increasing the capacity. The trade off with using cylinder nozzle orifice plates is they introduce pressure drop.

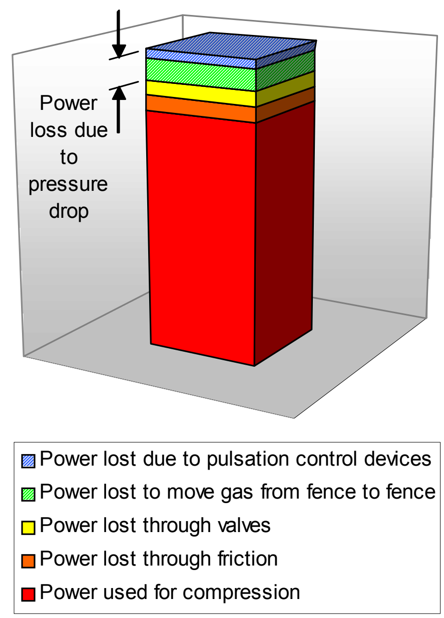

Figure 7. Breakdown of power loss

7.3. Pressure drop and power loss

The compressor driver power is used not only for compression, but to move the gas from fence-to-fence. Power is also lost due to the introduction of pulsation control devices, mechanical friction, and valve losses.

OEM or third party performance software requires an assumption for the power loss due to pressure drop, which will include the pressure drop through any pulsation control devices like orifice plates, baffles, and choke tubes. API 618 requires that pressure drop created by pulsation control devices must be kept between 0.25% and 1.67% of line pressure, depending on stage pressure ratio of the compressor. This should be taken into account when using performance software at the planning stage of compressor selection.

The fence-to-fence pressure drop is often assumed to be a constant percentage of line pressure. In reality, pressure drop varies with other factors, as shown in the formula below. A more accurate assumption would be to assume a pressure drop for the design condition and then vary that pressure drop with the formula below for all other operating conditions. Making the assumption that pressure drop varies with line pressure only can cause a significant reliability risk to meeting performance requirements.

$$\text{Pressure Drop} \sim \text{Gas Density} \times \text{Gas Velocity}^2$$

7.4. Dynamic pressure drop

Pulsations will cause an increase in the actual pressure drop from fence-to-fence. This is called dynamic pressure drop. As pulsations are controlled, dynamic pressure drop is reduced. A system with no pulsations will have no dynamic pressure drop. At some operating conditions, dynamic pressure drop can significantly alter the compressor performance, by increasing pressure drop.

In some cases, it is worthwhile to completely recalculate the compressor performance using the actual static and dynamic pressure drop (which may be significantly different than that assumed in the initial performance calculations at the planning stage) to see the affect on performance.

8. CHOOSING OPERATING CONDITIONS

In Section 4, the question was asked: Are two conditions enough to adequately identify the “complex” reliability risk to Compressor “Q”? This section will answer that question.

During the planning stage, many operating conditions may be run to generate load curves and to fully understand the boundaries of the reliable operating map, defined by the “simple” reliability risks. OEM or third party performance software can run thousands of operating conditions relatively quickly. Packagers, however, are typically only interested a few operating cases (e.g., design, rated, high flow, low flow) for their package design. These can be the extreme cases, from a performance point of view, but may not be the extreme cases from a pulsation point of view.

Torsional vibration studies, which identify a “complex” risk, tend to look at as many operating conditions as considered when evaluating “simple” reliability risks. This is because torsional studies involve relatively simple models, and the reliability risk of a failed crankshaft is very high.

Pulsation studies require a number of operating conditions slightly less than required for torsional vibration studies for two reasons: 1) pulsation studies are more complex and therefore take more computational time, and 2) the reliability risks due to pulsations tend not to be as severe as for a torsional vibration study. A pulsation study can reasonably deal with 300 operating conditions (or less if there are multiple units and/or significant off-skid piping) before time constraints make it impractical to consider more.

8.1. Number of load steps

As mentioned in Section 7, unloading has the largest effect on pulsation levels, therefore all unloading permutations (of volume pockets and valve unloaders) should be considered during a pulsation study. However, since pulsations from different stages are typically isolated from one another due to large volumes such as pulsation bottles, scrubbers, secondary volumes, and cooler headers, the number of unloading permutations, or *load steps*, can be reduced.

$$NLS = 2^{NVU} \times 2^{NVP}$$

NLS	= number of theoretical load steps (or actual load steps, if known)
NVU	= maximum number of cylinders on a stage with valve unloaders
NVP	= maximum number of cylinders on a stage with volume pockets

For example, Compressor “Q” has two cylinders with valve unloaders and two cylinders with volume pockets on stage one. On stage two, there is one cylinder with a valve unloader and two cylinders with volume pockets. Therefore, the number of theoretical load steps for stage one is **16** and for stage two is **8**. Of course, if the actual number of load steps is known, then use that number instead.

8.2. Minimum number of operating conditions

At a minimum, the extremes of the ranges for pressure (absolute), specific gravity, suction temperature (absolute) and load steps should be considered in a pulsation study. Some intermediate values can be chosen for pressures, specific gravities, and temperatures, if required. If we assume only the extreme values are chosen, an estimate for the minimum number of operating conditions for an accurate pulsation study can be calculated using the following formula. Note that a parameter can be considered “fixed” if it varies less than +/-10%.

$$NOC_{MIN} = NPS \times NPD \times NSG \times NTS \times MAX(NLS)$$

NOC_{MIN}	= minimum number of operating conditions for pulsation study	
NPS	= 1 if fixed suction pressure	= 2 if variable suction pressures
NPD	= 1 if fixed discharge pressure	= 2 if variable discharge pressures
NSG	= 1 if fixed gas specific gravity	= 2 if variable gas specific gravities
NTS	= 1 if fixed suction temperature	= 2 if variable suction temperatures
MAX(NLS)	= maximum number of load steps from any stage, or actual load steps	

Compressor “Q” has variable pressures, but a fixed suction temperature and gas composition. The maximum number of load steps from any stage was 16 (i.e., the maximum of 16 from stage one and 8 from stage two). Therefore, the minimum number of operating conditions for an accurate pulsation study, NOC_{MIN}, is **64**.

This number should be considered a guideline and not a rule. Pulsation consultants have procedures and experience which help judge which operating conditions may be the worst case. However, comparing this number to the number of operating conditions considered in the pulsation study report will give an indication of how thoroughly the reliably risks due to pulsations have been considered. Looking at the appropriate number of operating conditions has a relatively low impact on the cost of a pulsation study.

9. COMPRESSOR "Q" REVISITED

Two operating conditions do not seem enough to adequately identify the "complex" reliability risks to Compressor "Q".

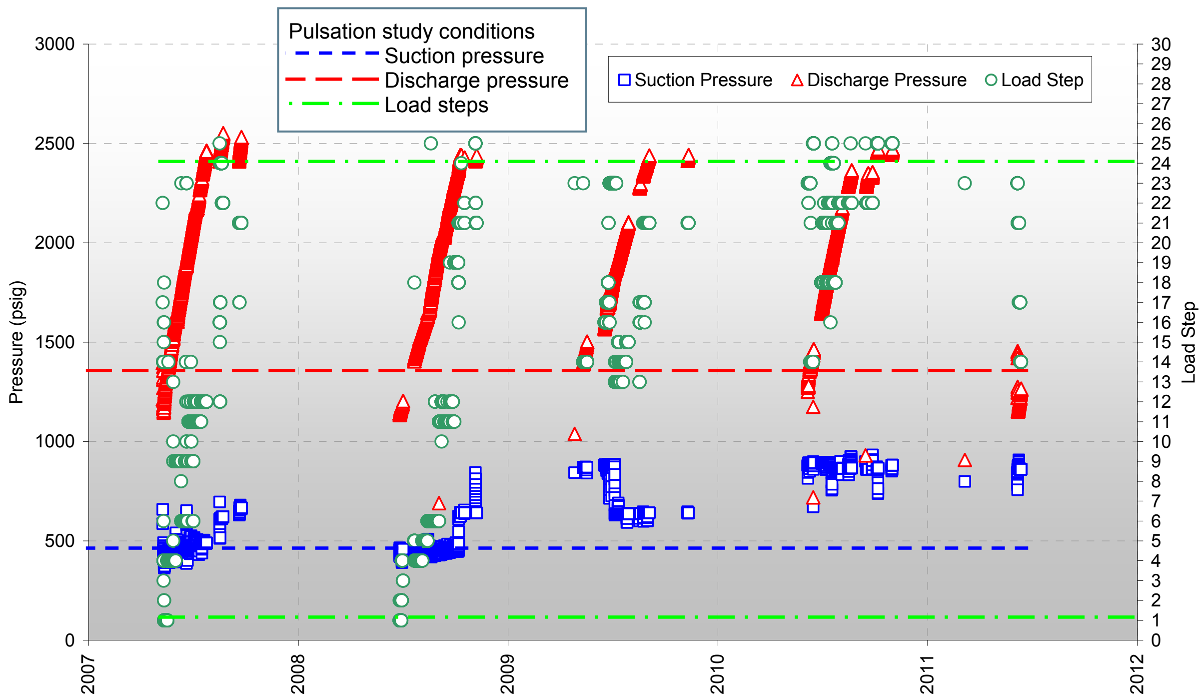

Figure 8. Historical operating conditions for Compressor "Q"

Compressor "Q" has been running for over 4 years. The historical data for the unit, showing the pressures and load steps, is shown in Figure 8. The two operating conditions considered in the pulsation study are represented by the four lines in the plot: suction pressure of 486 psig, discharge pressure of 1302 psig, and two load steps (load step 1 = fully loaded, load step 24 = almost fully unloaded).

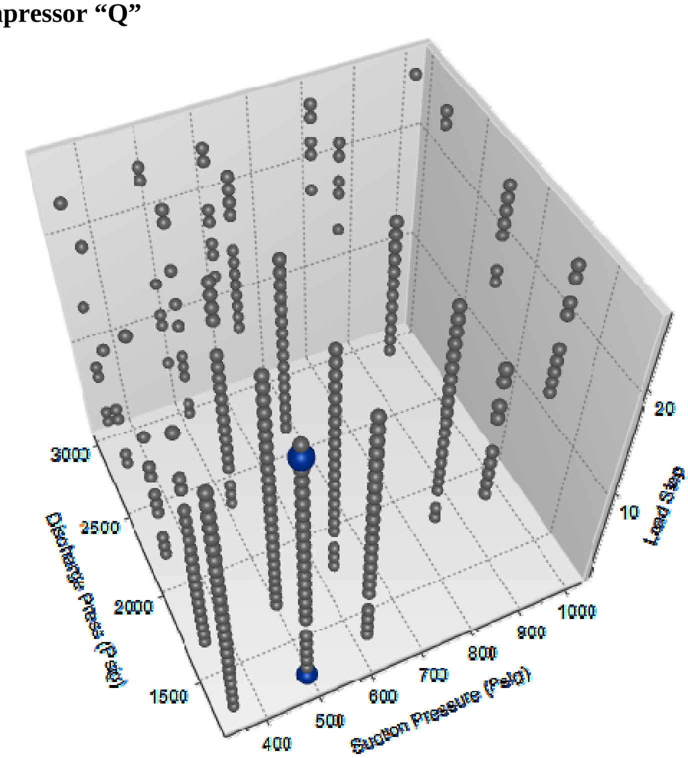

Figure 9. Historical operating map for Compressor "Q"

It is easier to understand where these two pulsation study operating conditions fall in the range of actual operating conditions by using an operating map. Figure 9 shows all the historical operating conditions plotted in three-dimensions. The suction and discharge pressures are on the horizontal plane and loads steps are on the vertical axis. The two pulsation study conditions are shown in blue, while all the actual operating conditions are shown in gray. There are gaps in the operating map because this map discards those conditions which have "simple" reliability risks such as driver overload and high rod load.

Now the full picture of the "complex" reliability risk due to pulsation-induced shaking forces can be developed. In general, the higher pressure and unloaded (i.e., lower capacity) conditions tend to have higher pulsations and, therefore, shaking forces. For example, the plot of the first stage suction lateral piping shaking force is shown in Figure 10. The two conditions evaluated in the pulsation study are circled, and are both under guideline (using API 618 5th edition piping guideline). However, the operating condition with the worst case force is 1.8x guideline (the starred point in Figure 10).

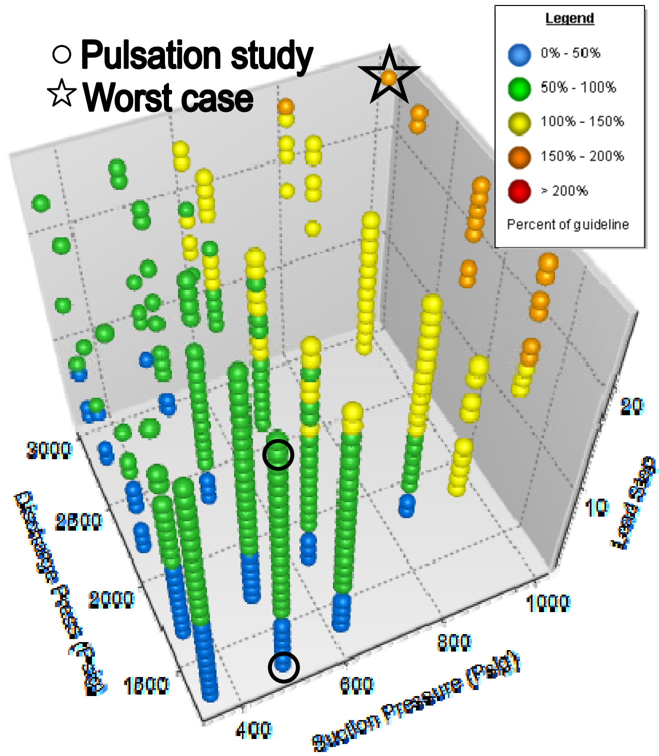

Figure 10. Compressor "Q" stage 1 suction lateral force

As shown in Table 1, high shaking forces can present a short term failure risk if the stresses in piping, vessels, and equipment are above the endurance limit, and can be a medium term failure risk if they cause vibratory loosening of bolts or failure of non-critical components (such as clamps). A balance between reliability risks, capital costs, and pressure drop needs to be considered before judging this shaking force as unacceptable. Early in the design process, the suction pulsation bottle size could be changed or the bottle internals could be altered to lower the lateral piping shaking force. Later in the design process, orifice plates may need to be used to control pulsations or more robust clamps could be used to counteract the higher forces. These would impact pressure drop (performance) or capital costs, respectively.

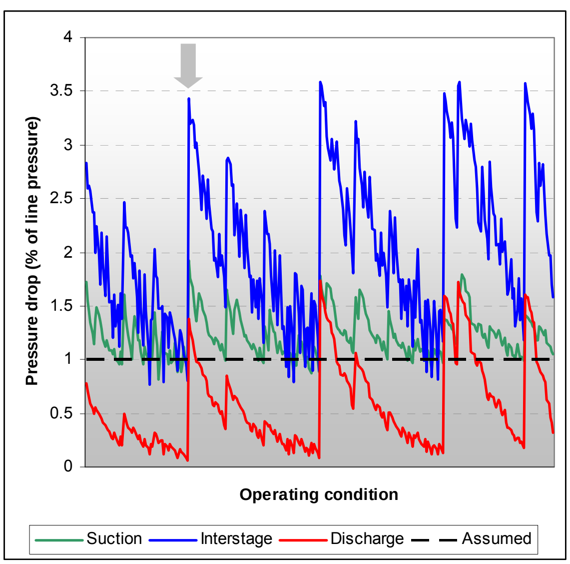

Figure 11. Compressor "Q" actual vs. assumed pressure drop

There were other issues, but the reliability risk that had the most impact for Compressor "Q" was a performance issue. Shortly after startup, the operators started getting unexpected overload alarms from the Caterpillar fuel-horsepower calculations. A third-party was contracted to take analyzer readings on the compressor and compare it with the compressor PLC model. What was found was that the discharge temperatures were higher than predicted, the analyzer calculated clearances were higher than specified by the OEM, and the analyzer measured horsepower was more than the OEM predicted. After some investigation, it was found that the pressure drops introduced by the compressor cylinder nozzle orifice plates were not accounted for in the performance software or in the compressor PLC model. After the actual fence to fence pressure drop was considered, the actual performance matched the OEM performance predictions, and the compressor PLC model was tuned so the overload alarm was prevented.

The reliability risk to Compressor "Q" was a performance risk which was caused by a higher than assumed pressure drop. The fence-to-fence pressure drop was assumed to be 1% of line pressure; Figure 11 shows the actual fence-to-fence pressure drop. Even the design condition, indicated by the arrow, was significantly over the 1% assumed. In retrospect, if this reliability risk was identified initially, a larger driver could have been used.

10. RELIABILITY RISKS AND DESIGN PROCESS

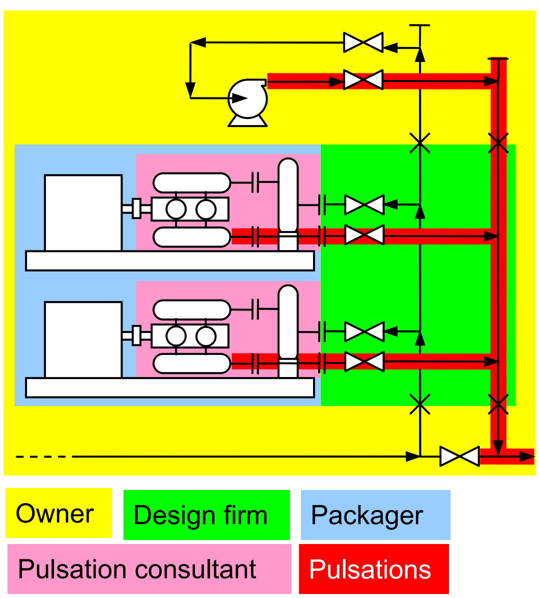

Figure 12. Areas of responsibility

Most of this paper has been discussing reliability risks and the various analyses which can predict and mitigate these risks. There are also two process changes which can help reduce reliability risks, or, at a minimum, help reduce their impacts.

First, as discussed in Section 4, different groups involved in planning and designing a compressor installation have different priorities and responsibilities. In some cases, the delineation of responsibility may be arbitrary, or worse, unclear.

One typical breakdown of responsibility is for the compressor packager to be responsible for the compressor and any piping within the package limits ("on-skid"). The packager may sub-contract a pulsation study to a pulsation consultant.

In reality, pulsations travel outwards, in the main process piping, outside of the compressor package limits, into the headers and beyond. If there are other units connected to the same piping system, they will be affected by the pulsations and may suffer reliability risks due to pulsations. In Figure 12, the pulsations created on the discharge side of the two reciprocating compressors extend beyond the on-skid piping into the off-skid header, interact with the discharge of the centrifugal compressor, and continue into the pipeline.

Expanding the scope of the pulsation study to include all areas affected by pulsations (not just on-skid piping) will help reduced the reliability risk due to pulsation.

Second, by getting the pulsation consultant involved earlier in the planning and design process, the reliability risks can be identified earlier. Early identification helps reduce capital costs of design changes and helps lower the pressure drop of pulsation control devices. Also, having the owner working directly with the pulsation consultant will help avoid miscommunication. For example, if the compressor operating conditions change, then the pulsation study can be updated to account for this. Also, the actual pressure drops can be summarized and used to re-run the compressor performance.

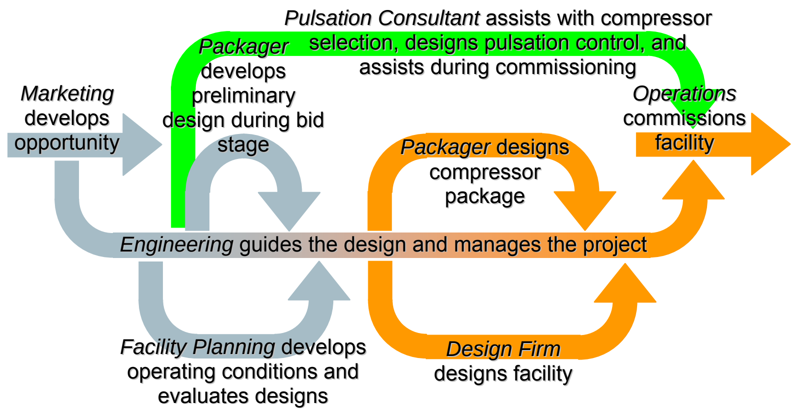

Figure 13. Updated project flow diagram

A modified design process flow is shown in Figure 13, which will help reduce the reliability risks due to pulsations and vibrations. The pulsation consultant can also verify reliability risks in the field during startup by checking pulsation and vibration levels.

11. CONCLUSIONS

Performance and reliability risks of a reciprocating compressor need to be considered at the planning stage. Some reliably risks can be identified simply and some require detailed studies to be identified. The sooner the reliability risks are identified, the easier it is to mitigate them and the impact on capital cost and performance are minimized.

Pulsations can affect the reliability of a reciprocating compressor by creating shaking forces which may cause vibration and failure, and by affecting the compressor valve which affects valve life and compressor performance. Also, pulsations will create dynamic pressure drop which can affect compressor performance.

Having the pulsation study consider an adequate number of operating conditions is one tool to ensure the reliability risk due to pulsations is minimized. Other tools include adequately defining the scope of the pulsation study to include off-skid piping, and clear communication between parties when critical information is changed or calculated. Also, getting the pulsation consultant involved early, and directly with the owner, will help ensure a reliable unit.

12. REFERENCE

- Engineering Data Book, "Section 13 – Compressors and Expanders," 12th Edition; Gas Processors Suppliers Association, 2004.
- API Standard 618, "Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services," American Petroleum Institute, 5th Edition, December 2007.
- Adam Long, Dwayne A. Hickman, Shelley D. Greenfield, and Hemanth Satish, "Improved Performance of a Pipeline Compressor Station," Gas Machinery Conference, 2009.
- Jeff Dowdell, Scott Schubring, Bret Grier, Noah Dixon, Bruce Howerton, Dwayne A. Hickman, Joe Fernandez, Travis Sixel, and Jack Smith, "Developing an Effective Approach for Sizing Reciprocating Compressors," Gas Machinery Conference, 2010.
- H. Paul Barringer, Michael Kotlyar, "Reliability of Critical Turbo/Compressor Equipment," First International Conference on Process Plant Reliability, 1996.