Vibration and Pulsation Analysis and Solutions

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Problems created by excessive vibration in machinery can have serious economic impact. Frequently these problems are caused by large pressure pulsations in associated piping.

This presentation shows some examples and then describes how specialized analysis techniques can be used to prevent such situations.

Objectives of Specialized Analysis

- control of exciting forces
- control of mechanical system response
- ensure reliability, performance and ROI

The application of specialized modelling and analysis techniques can greatly reduce the risk of vibration related problems

Generally, the analyses seek to optimize the design in two ways:

1) By ensuring that dynamic excitation forces are acceptably low. For example, forces due to pulsations in piping systems.

2) By limiting the response (vibration and dynamic stress) of the mechanical components. A key requirement is to eliminate coincidence between mechanical natural frequencies and excitation frequencies.

However, it is important that this design optimization exercise take account of capital costs and of operating costs and efficiencies. One common practice is to control pulsations in piping systems simply by introducing pressure drop; i.e. orifices. This can be counter productive since the cost of the pressure drop can exceed the benefit realized.

Greater Need Than Ever

- higher speeds causing new problems
- forcing functions:
  - >> cylinder passage forces
  - >> crosshead forces
- standard mechanical design inadequate
- problems have more serious consequences

New problems have arisen as a result of higher machine speeds and resultant shorter pressure pulsation wave lengths. Mechanical natural frequencies need to be higher than ever to get around the higher frequencies of the unbalanced forces and moments inherent in reciprocating compressors.

Forces caused by pressure pulsations in the cylinder passages of compressors show up at the half-wave frequency of the gas passages. These cylinder forces are at high enough frequencies that they are now occurring at the mechanical natural frequency of the cylinder-distance piece-frame assembly. Attachments on the cylinders, such as pockets and inboard supports, are subjected to more severe environments as a result.

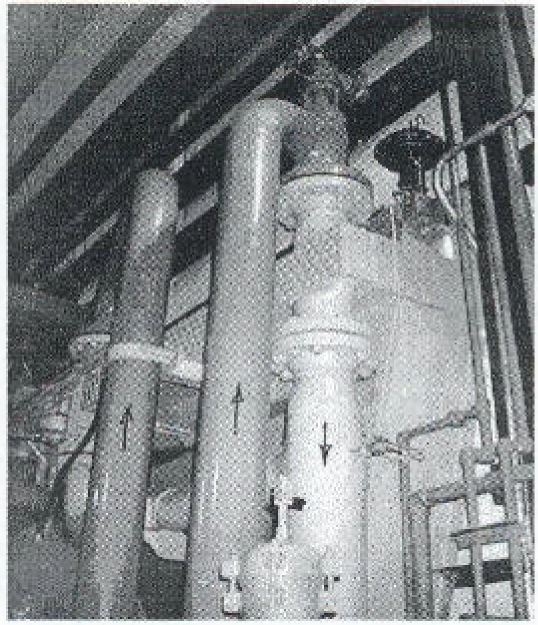
The forces acting in the vertical direction through the crosshead guide are proportional to speed squared and reciprocating mass. The higher speed and still large reciprocating inertia's cause the crosshead forces to increase rapidly.

Preventing problems is more difficult because

-in the search for more flexible operation, greater speed variation is designed into systems. There are fewer potential solutions (frequency ranges of orders overlap, so "tuning" must be very precise)

-mechanical modelling accuracy at high frequencies is more difficult. The flexibility of flanges becomes significant, for example. On slow speed compressors, a flange was modelled as a rigid pipe.

Broken Cooler Nozzle



This is an example of the consequences of not utilizing dynamic modelling in the design stage. The cooler nozzle under the relief valve in the photo was cracked due to vibrations caused by pressure pulsations. The crack was on the side that could not be reached (Murphy at work!)

The crack resulted in a shutdown of the failed unit and the spare unit (out of concern that it too would fail). Lost production was costing over US$10,000 per day. The emergency callout of the trouble-shooter on Boxing Day cost something as well.

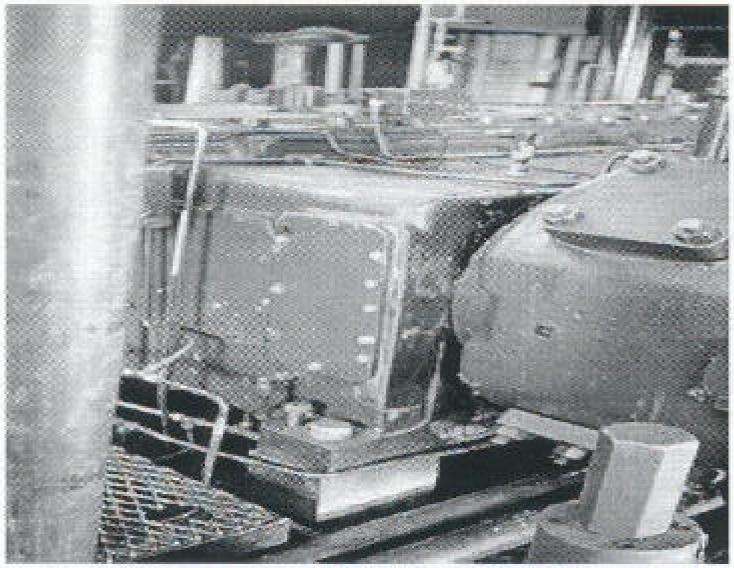
Every attempt to control the vibrations in the field using ad hoc approaches (orifice plates, braces, removal of pipe strain, added pipe supports) was of some help, but the net result was that the unit could only be safely run at one speed in the intended 700 to 1200 rpm range.

A computer analysis of the acoustic pulsations in the piping systems showed very high shaking forces throughout the system. It was clear why the system had not been tameable in the field.

Many different changes were attempted on the computer before settling on new and much larger pulsation dampeners. The cost of building and installing these new vessels was in the order of $100,000 dollars. The cooler nozzle repair cost several days and many thousands of dollars.

The packager of the system was aware that this type of problem could occur without proper design. The end user chose not to pay for the extra design costs.

Broken Compressor Frame

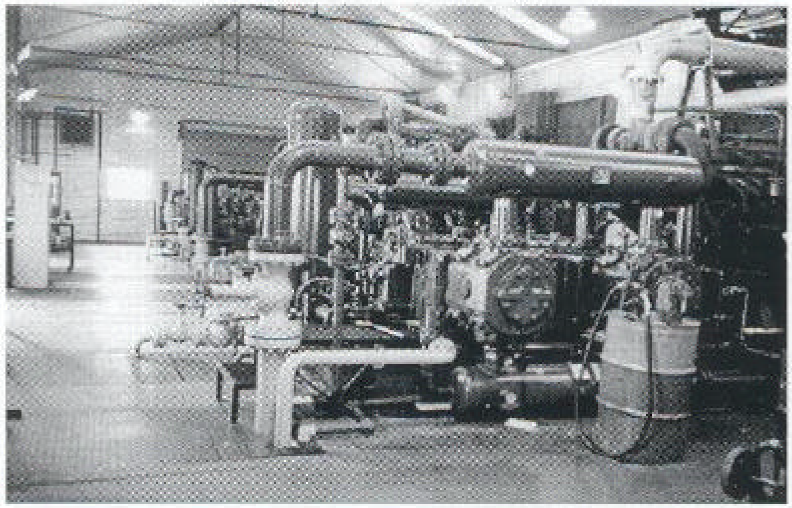


A second illustration. A compressor frame repair is shown in this photo. The cast material was stitched together in the area without paint.

No new frames were available. No used frames were available.

The compressor was unavailable for the period of repair. The cause of the failures and the likelihood of the weakened frame failing again were unclear to the operators.

Broken Compressor Frame (continued)



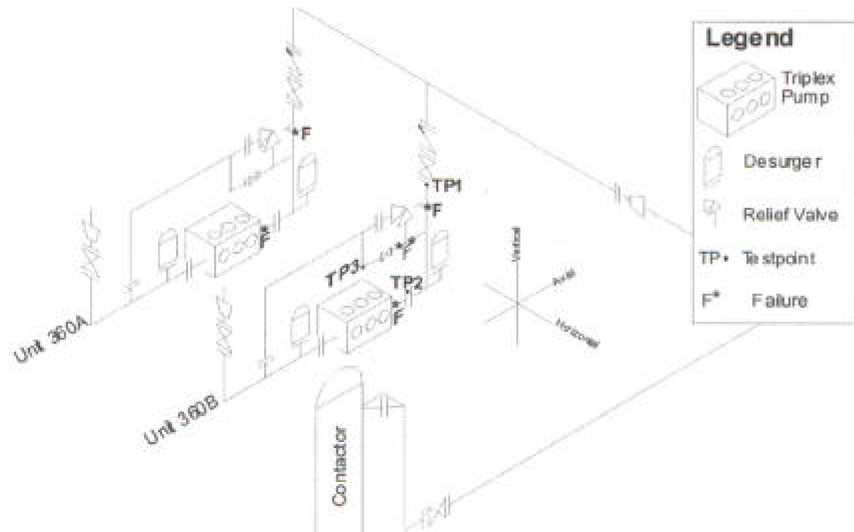
This is a view of the free-standing elbow at the bottle inlet. The elbow was vibrating in a direction parallel to the piston motion The unit had not been a problem when it was operating at lower speeds. Demand for gas increased and the compressor speed was increased. Then the mechanical natural frequency of the pipe was excited by the cylinder assembly motion. The very high vibrations resulted in stresses that cracked the frame.

This was not a pulsation problem! The vibrations were not caused by pressure pulsations in the bottles or piping. Rather, they were caused by the gas forces inside the cylinder which make the cylinder assembly get longer and shorter.

Design of such a system should include estimation of the mechanical natural frequencies of free standing elbows. This problem could have been avoided.

Alternatively, a start-up check of the vibrations of the piping could have detected this problem before it caused the frame failure.

Piping Failure Example



This is an example where piping failures occurred in a plunger pump installation pumping amine through a contractor to sweeten natural gas. The piping failed repeatedly. Each time, about $5000 worth of amine was lost. In amine costs alone, over $60,000 was lost. Lost production, labour, etc. was as much more. Changes to the system were repeatedly implemented on a trial and error basis. Bladder desurgers were added. The locations were changed. Nothing worked.

During our first visit, the noise emitted by the pump was obvious. Vibrations were high on the small bore piping when overall vibrations were measured. The frequency domain data showed no specific problem

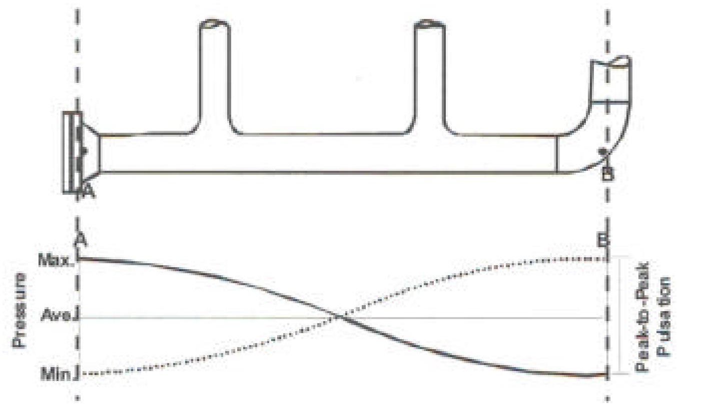
Pressure measurements indicated that the pump valves were closing late. The late closure of a suction valve causes slamming of the discharge valve on opening, and vice versa. The plates hit the backguard and damaged the valve. All of the bad valve dynamics resulted in high pulsations and vibrations.

Although it is counter-intuitive, the solution involved putting in stiffer springs in both the suction and discharge valves. At start-up during our second visit, the pumps were so quiet that we checked the flow meter to see if the pump was vapour locked. The operator quickly concluded that the pump was pumping more than before. The vibrations were similarly improved. No failures have occurred since.

A start-up check by a knowledgeable technician would have saved a great deal of time, money and frustration.

Why Worry About Pulsation?

- can generate excessive force



Pulsations in piping and vessels are a very common source of excessive vibrations and resulting problems. If half the wave length coincides with a length of pipe, or a bottle, potential forces are enormous.

e.g. 5% pulsation, 14" pipe, 2600 psi pressure: over 20,000 lbs. Alternating force. On a 1200 RPM machine, if this is a pulsation at two times operating speed, which is very common, then the force reverses 2400 times per minute. This would almost certainly lead to the failure of anchor bolts, clamps, supports, etc, and quite possibly to a piping failure also. Obviously, the pulsation has to be reduced.

Forces due to pulsations can cause unacceptable forces in the vertical direction on cylinders. This is a little-understood phenomenon. The most used standard for pulsation design, API 618, does not even include a guideline for this part of a reciprocating compressor piping system.

Pulsations cause flow fluctuations too. Metering error can result. Increased system pressure drop results from flow fluctuations, adding to the operating costs of a compressor.

Pulsations can cause distortion of the pressure-volume curve of a compressor, resulting in lost production or increased operating costs. If the compressor is operating at full capacity, lost production can be extremely costly.

Available Options – Design Stage

- Standard experience based design or
- Analyze and optimize design
  - control pulsations through acoustical modelling
  - eliminate coincidences of MNFs with main forcing functions

Utilizing specialized dynamic modelling and design is proactive risk management.

If you implement a standard, experience-based design, it might work acceptably well. But there is substantial risk that there will be problems which impact reliability, performance, safety and profitability. In such cases the cost to correct the problem and the cost of lost or delayed production are usually very large – see the examples above.

Design optimization will greatly reduce the risk. The reduction in risk will commonly much more than offset the small increase in capital cost.

Considerations that help to make the decision to include analysis in design work before construction include: the criticality of the machine, cost of lost production, safety risks, fraction of rated load, newness of the design, location and accessibility of the unit, etc.

(piles are hard to add after the fact. Platforms offshore are hard to reach.)

Available Options – Existing Unit

- avoid the problem operating condition(s)
- trial and error to fix the problem
- mechanical and acoustical models
  -- to identify most cost effective repair

With existing equipment that has vibration related problems, the same design approach should be used to find the most cost effective solution.

Avoiding the problem operating condition can help, and might be the best option temporarily. In most cases, however, it will be necessary to introduce permanent corrections in order to achieve your performance (and economic objectives.)

As a minimum, it is important that the state of vibrations of machines and piping systems be understood as soon after start-up as possible. If no problems are detected, then a useful baseline will have been recorded against which future changes can be compared.

If problems are detected, they can be dealt with before costly damage and lost production occur.

Ensuring Project Success:

- sound basic design plus…
- limit forces in the system via acoustic modelling
- mechanical design optimization through analysis
- construction which follows the design
- start-up checks and fine tuning if required.

To review and summarize:

Make sure the mechanical design is appropriate,

Piping should be low and well supported; bottle appendages close to vessel; supports for relief valves, etc.

Model doubtful areas and solve problems ahead of time.

Make sure forces in the system are reduced as much as possible. Modelling is the most cost effective way to do this – unless you are risk oriented. Some compressors have no problems; those that do can cost hundreds of thousands of dollars in field fixes and delayed start-ups.

And even the best design is inadequate if it is not implemented correctly. For example, pipe bolt up strain must be small.

Result ….

- low vibration levels
- efficient operation
- low stress levels
  -- in compressor, piping and project manager
- financial success

Dynamic modelling and analysis as a component of design will contribute to the above benefits.

During start-up, field analysis of vibration, pulsation and performance will further contribute to assuring economic success.

Where problems are present in existing machinery, the same approaches can be used to re-design the unsatisfactory original design.