June 2010 Volume 19-1

the BETA BULLETIN

BETA
MACHINERY ANALYSIS

ENGINEERING & DESIGN SERVICES
FIELD SERVICES
OPTIMIZATION SERVICES

This issue in Brief

BETA celebrates an accomplishment by working safe and smart!

In their travels around the globe, our troubleshooting staff have seen a lot of vibration problems caused by plunger pumps (also known as reciprocating, diaphragm, or positive displacement pumps) and there is growing concern around this issue.

Ask the Expert looks at the importance of using the correct software tools (finite element models), and we have a centrifugal compressor case study for you.

Working Safe and Smart

BETA has achieved a Certificate of Recognition for its Environment, Heath and Safety programs to meet our global customers' requirements.

Ron Carpendale, champion of BETA's safety initiative

Complying with the OH&S legislative requirements of an international marketplace is a major business challenge. Beta's proactive compliance to these requirements makes it easy for us to be your preferred supplier for vibration, performance and troubleshooting services.

BETA is pleased to announce the results of the certification audit of the Company's OH&S Policy, Program and Safe Work procedures. "Beta Machinery Analysis has successfully completed a Large Employer External Audit in accordance with the Alberta Safety Council Partnerships Audit Process for their Certificate of Recognition (COR) and the audit has passed with flying colours." BETA has been issued a COR Certificate number of 20091120-4835. Ron Carpendale, BETA's Operations Manager has led the development of our internal safety programs and is a certified internal OH&S auditor.

BETA has maintained excellent safety performance statistics through our 43 years of business. In 2005, BETA first responded to the Safety initiatives of our clients and subscribed to several "Vendor Management" services such as Canada HSE, PEC Premier, and ISNetworld. Through the efforts of BETA's Joint Environment, Health and Safety committee and the third party competency training providers, we maintain 100% compliance to the review and verification requirements of these "Vendor Management" services.

BETA's Field Service personnel physically respond to our customers' requests for engineering services on all continents. BETA has aligned its OH&S capabilities with the expectations of all of our customers.

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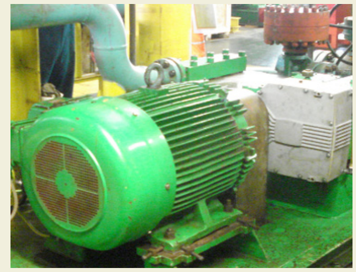
Positive Displacement (Plunger) Pumps

What you don't know CAN hurt you.



Positive Displacement or Plunger Pump

Positive displacement pumps, also known as plunger pumps, are used in many applications. These pumps create dynamic pressure pulsations which interact with the piping system creating acoustical resonances, which, in turn, cause problems:

- High pressure pulsation-induced forces in piping may trigger excessive vibration and piping failures,
- High pressure pulsation at the relief valves may lead to pressures exceeding the opening pressure setting of the relief valve, and
- Pressure pulsation may result in pressures inside the pump chambers, at the suction valves, inside the suction manifold, and in the piping, dropping so low that bubbles of gas form (cavitation).

Pump Pulsation Study Application Guide

We have worked on many platforms in SE Asia and other facilities, addressing pump problems, which are becoming major operational issues. To mitigate these issues, a pulsation study, as required by API 674 is recommended. Depending on the application, the pulsation analysis may require a mechanical analysis.

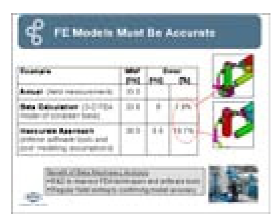
There are three different approaches for a pulsation analysis. To help customers determine the appropriate scope, we put together this useful two page Pump Pulsation Study Application Guide available on our website www.BetaMachinery.com .

Ask the Expert

Are there truly differences in FE Models?

A valid question. It is easy enough to produce predictions of dynamic behavior, but it is quite challenging to produce accurate results.

As background, BETA has executed hundreds of field projects to investigate and correct compressor and piping vibration problems. A few of these have been in systems that we modeled. In the early days, we employed simple models, beam elements, and often assumed rigid boundary conditions. Because of our field work, we quickly learned that these simplified models were not good enough. We made it a priority to measure actual mechanical natural frequencies (MNF) and vibration levels, and compare against predicted values whenever we have the opportunity. Not all machinery consultants do this.



Proper Tools are Essential for Accuracy

Using detailed 3-D FEA models, the results reported by BETA are impressive; for example, agreement between predicted and measured mechanical natural frequencies at a frequency near 160 Hz is not easy, yet BETA accomplishes this.

In another example, BETA's calculation of MNF (33.6 Hz) was within 1.8% of the actual vibration (33.0 Hz), compared to the 16.7% difference (38.5 Hz) where inferior software tools were used and poor modeling assumptions were made.

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When modeling and predicting vibration and dynamic stress levels our forced response studies are thorough. All modeling is imperfect and we continuously look for improvements. Because BETA does so much field work, we are in a better position than many organizations to fine tune our procedures based on measured behavior versus predicted. We are not only competent at dynamic modeling of structures and machinery systems, but in fact are leaders in the field. See our web site, www.BetaMachinery.com, or contact us for more information.

Bryan Long, PhD
Director of Business Services

Centrifugal Compressor Case Study

Summary

In 2008, three centrifugal compressors at this compressor station were retrofitted with higher head impellers. For the next two years the owner experienced continual vibration problems that caused failures with RTDs, transmitter and position switches. Most of the failures were on the discharge side, but failures did occur on the suction side as well. The cause of the failures was assumed to be flow induced pulsations (also referred to as vortex shedding). Many attempts were made to modify the thermowells and RTDs, but they were not successful in reducing the failures.

In early 2010, Beta Machinery Analysis traveled to the site and conducted a vibration and pulsation analysis. After assessing the situation, it was determined that excessive shell mode piping vibration was responsible for the problems and not flow induced pulsations as original assumed.

This case study outlines the factors that contributed to the vibration problem and recommended solutions. It also highlights why a centrifugal vibration study may be good practice during the initial design (or retrofit). This study predicts interferences between the compressor and shell mode piping natural frequencies and potential excitation sources such as flow induced or, and, blade passing pulsations. It is much easier and less costly to make adjustments at the design stage compared to searching for, and solving, the problem in the field.

Figure 1: One of three centrifugal compressors that experienced vibration problems due to mechanical and acoustical resonance

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Vibration and Pulsation Problems

The vibration and pulsation on the unit increased significantly when the compressor was run at or near full speed of 4500 rpm. The operating condition was just off the best efficiency point of the compressor.

As shown in Figure 2, the vibration levels were as high as 1.5 ips pk on the discharge piping and varied around its circumference. This is equivalent to an estimated 30g pk at blade passing frequency. This vibration amplitude is above recommended guidelines for the piping system.

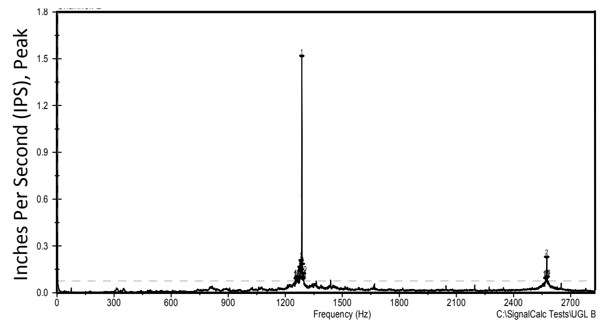

Figure 2: Vibration on Compressor Discharge Piping

Sources of Vibration Problems

The primary vibration sources on centrifugal compressor systems include:

1. Pulsations due to Blade Passing Frequencies
2. Vortex Shedding (Flow Induced Vibration)
3. Surge

1. Pulsations due to Blade Passing Frequency

The main excitation source in this case was due to the blade passing frequency. The primary frequency of vibration was at blade pass frequency, 1260 – 1280 Hz (17X run speed) and the secondary frequency of vibration was at twice blade pass frequency (34X run speed).

On the discharge side the pulsation was as high as 20 psi pk-pk at blade pass with the overall pulsation being 30 – 40 psi pk-pk. On the suction side the frequency content was the same as the discharge, but with lower amplitudes.

2. Vortex Shedding (Flow Induced Vibration)

Two kinds of vortex shedding problems can develop in centrifugal compressor piping systems.

i. Dynamic forces from vortices generated behind thermowells can resonate with the mechanical natural frequency (MNF) of the thermowell; thermowell failures causing gas leaks can result.
ii. Vortices across the open end of side branches without mean flow can excite acoustical resonances in the piping, which can, in turn, excite MNFs of the piping. Unacceptably high piping vibrations result when resonances develop [ref 1]. Flow-induced vortex shedding can also excite the torsional natural frequency [ref 2].

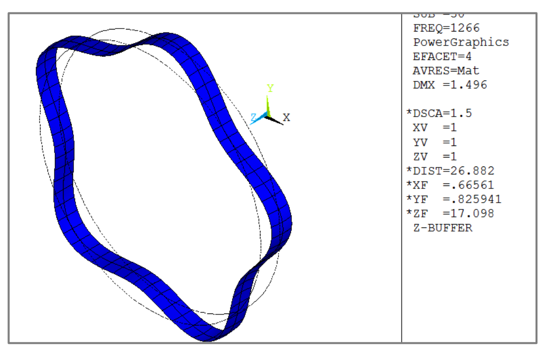

Figure 3: Selected ring to show the 5 lobes of the mode shape

Both can be avoided using proper techniques in the design stage. In this case study, it was determined that the failures and vibration problems were not due to vortex shedding.

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3. Surge

Surge in a compressor creates large, low frequency pulsations and vibrations. However, avoidance of surge is much more important than mitigating short term vibrations that result.

Pipe Shell Mode Natural Frequency

The calculated natural frequency for a 5 lobed circumferential mode shape was approximately 1266 Hz as shown in Figure 3 and in the interference plot, Figure 5.

Stress Levels

A finite element model was used to determine stresses in the pipe shell when the mode was excited using actual measured displacements as shown in Figure 4. That calculated stress was well below the endurance limit for carbon steel pipe. Although this indicates there is a very low probability of failure of the pipe itself, the excessive pipe vibration causes serious problems with branch attachments, leading to the failures.

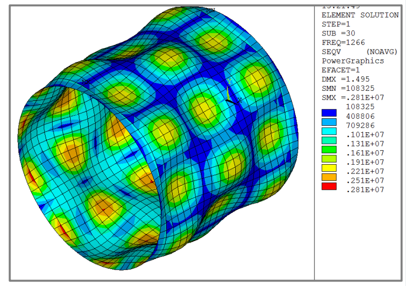

Figure 4: Piping mode shape

Acoustic Natural Frequency

At the discharge conditions, the speed of sound is 1430 ft/s. With that speed of sound, the discharge pipe has a transverse acoustic natural frequency of <u>1260 Hz</u>. The mode shape <u>matches</u> that of the pipe shell mode natural frequency.

Interference Plot

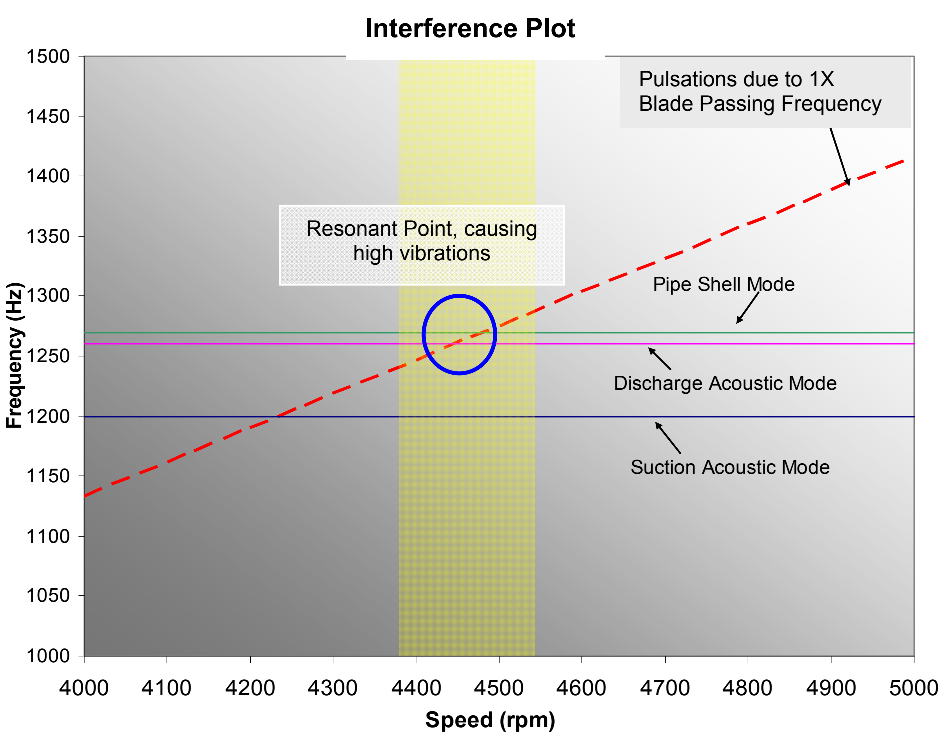

Figure 5: Interference plot

Figure 5 is an interference plot showing the coincidence of the discharge pipe shell mode, acoustic natural frequency and blade passing frequency at a compressor speed of approximately 4400 – 4500 rpm.

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It was concluded that the piping was resonant because the shell mode (natural frequency) is coincident with 1X blade passing frequency of the impellers (17X Run Speed). The vibration was aggravated because the acoustic natural frequency also occurs at this same blade passing frequency. Additionally, the mode shapes are such that the mechanical and acoustical natural frequencies are well coupled making the piping responsive to the input energy.

If both the shell mode and acoustical natural frequencies had been well separated from each other or from the pulsation frequency, then the vibration response would have been greatly reduced.

Possible Solutions

Three solutions were identified to resolve the piping vibration:

- Changing the aerodynamics of the compressor internals to reduce or eliminate the pressure pulsations.
- Stiffening the piping to move the shell mode frequency away from resonance.
- Adding splitter plates to the inside of the pipe to change the acoustic natural frequencies of the system away from resonance.

The customer is currently evaluating these options and will begin implementing changes in the near term.

Conclusion

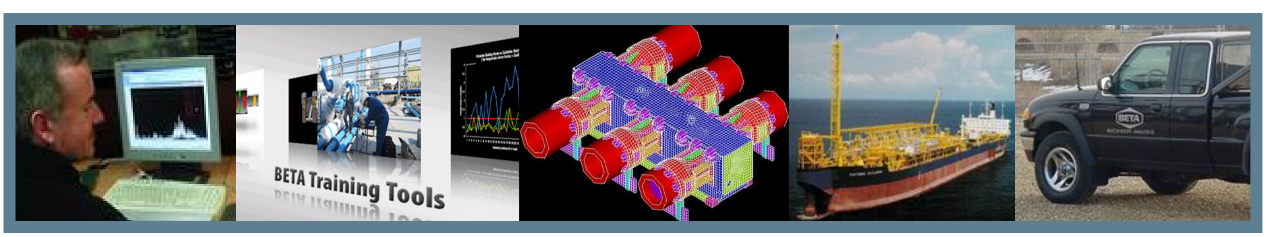
This example illustrates that severe vibration problems can occur on centrifugal compressors due to the interaction of the excitation force (pressure pulsations at blade passing frequency) with the acoustical and piping natural frequencies. Due to the expensive repairs and compressor downtime, vibration problems are very costly to the customer.

A good practice to avoid these problems is to perform a vibration study of the proposed layout during the design stage. A centrifugal compressor vibration study predicts interferences between natural frequencies and potential excitation sources such as, vortex shedding and blade passing frequencies.

References

A Case Study of Piping and Shaft Vibrations on a Centrifugal Compressor; Beta Machinery Analysis, William F. Eckert, P.Eng., Ph.D.; Brian C. Howes, M.Sc., P.Eng.

A Case Study of a Flow-Induced Torsional Resonance, William Eckert, Brian Howes, CMVA, 19th Proceedings on Machinery Vibration, Edmonton AB, 2001



Training Options

Check out our 'vibration on reciprocating compressors' training videos on http://www.YouTube.com!

Customized vibration training is available – in most cases, at your site. Ask about our lunch and learns and seminar options. Topics cover issues such as, Pulsation and Vibration in Reciprocating and Rotating Equipment, Understanding API 618, Torsional Analysis, Remote Monitoring, Troubleshooting Tips, and more.

Do you have comments or questions about any of this material? Do you have topics you'd like to see covered in the Beta Bulletin?

If so, send an email to:

jwalters@betamachinery.com.

Upcoming 2010 Trade Shows and Conferences

Oct 4-6 **Gas Machinery Conference (GMRC),**

Phoenix Convention Center, Phoenix, AZ,
Presenting two technical papers and one short course
Booth #419

Oct 5-7 **39th Annual Turbomachinery Symposium**

George R. Brown Convention Center, Houston, TX
Booth # 1331

Oct 20-22 **7th EFRC Conference**

Palazzo dei Congressi, Florence, Italy,
Presenting a technical paper and hosting a booth.

How to Contact Beta

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Pearls of Wisdom

If you don't learn to laugh at trouble, you won't have anything to laugh at when you are old.

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The reason a dog has so many friends is that he wags his tail instead of his tongue.

~ ~ ~ ~ ~

He who thinks he leads, but has no followers, is only taking a walk.

~ ~ ~ ~ ~

"The single biggest problem in communication is the illusion that it has taken place." George Bernard Shaw

BETA

MACHINERY ANALYSIS

Keeping it running smoothly