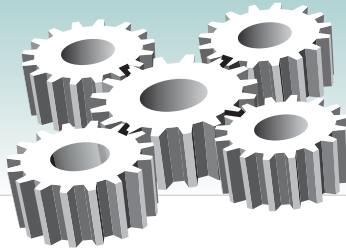




Machinery Analysis



THE BETA BULLETIN

VOLUME 10 #1

Beta Machinery Analysis Provides FPSO Design Services



TANTAWAN EXPLORER



FPSO stands for "floating production, storage and offloading". These are systems that are increasingly being used to produce oil from offshore reservoirs. A FPSO consists of three major systems:

Beta Machinery Analysis

- a turret, which is a non-rotating portion that provides anchoring and attachment to production risers and control umbilicals;
- the hull, basically like a tanker hull, (some are converted tankers) provides storage function; is free to "weather-vane" around the turret;
- the topsides equipment, providing processing, separation, chemical treatment, compression, utilities, etc.

Most FPSOs have compression as part of the topsides equipment. The compressed gas is re-injected for enhanced recovery or can be sold if a pipeline to shore is in place.

Designing reliable, efficient compressor packages for a FPSO is similar in many ways to a shore based system, but has some added complications. Dense packaging is needed for a small footprint. It is more difficult to ensure acceptably low vibration, particularly if reciprocating compressors are used.

This added challenge arises because the equipment is mounted on the ship main deck, which is lightly damped and has dynamic characteristics that can amplify the inherent shaking forces and vibration associated with a reciprocating compressor. Support systems for shore based compressors have much more damping and support systems that are more rigid and massive.

Prudent FPSO design includes extensive dynamic modelling and analysis of the compressor, piping, and supporting

structure. Acoustical studies predict pulsation levels and resulting dynamic forces. Mechanical modelling predicts vibration and dynamic stress levels in the piping and surrounding support and deck structure. Design refinements can then be implemented to limit the impact of these effects.

Testing during construction and at startup can provide further insurance.

Result - low probability of significant "show stopping" vibration or pulsation problems; a reliable, efficient compressor installation.

Beta Machinery Analysis has been involved in several of these projects. On the Tantawan Explorer project, BMA provided:

1. Complete acoustical and mechanical analysis of a single gas lift compressor, a single low pressure compressor, 3 intermediate pressure compressors, 4 sales gas compressors as per API 618 3rd Edition, Design Approach III. This included:
 - developing acoustical models of each system to design modifications that reduce pressure pulsations and acoustical forces to API and Beta Machinery guidelines;
 - developing mechanical models to design mechanical supports, pipe layouts and vessel details to avoid resonance related vibration problems.
2. Forced response analysis of the intermediate pressure and sales gas compressor off-skid piping. This included developing finite element

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One Shot Balancing Procedure

models of the piping from the compressor skid edge to the off-skid process vessels. Acoustical unbalanced shaking forces were input into the model to predict vibration and dynamic stress levels to determine if support modifications were necessary.

3. Quasi-static analysis of the intermediate pressure and sales gas compressor skid and sub-skid. This included developing a finite element model of the compressor skid and sub-skid to assess the deflections and stresses in the skid beams due to ship motion for storm and survival conditions.
4. Dynamic analysis of the intermediate pressure and sales gas compressor skid, sub-skid and support deck. This included design of the compressor sub-skid and modifications to the proposed support deck design to reduce vibrations due to forces in the compressor and engine. A finite element model of the compressor skid, sub-skid, support deck and ship web frame and bulkhead stiffness was developed. Mechanical natural frequencies for the model were calculated. Modifications were investigated to avoid resonance with integer multiples operating speed. Vibrations and dynamic stress were calculated for mechanical natural frequencies that could not be easily modified.
5. On-board testing of the intermediate pressure and sales gas compressor skids was conducted while the units were being constructed in the Sembawang Shipyard, Singapore. Practical limitations of any finite element model require that some assumptions and approximations be made. The testing was done to verify the boundary conditions and modelling techniques used in the analysis. Our finite element models were adjusted so that our results more closely agreed with the actual installation. The testing indicated some support decks would need additional modifications to ensure an acceptable dynamic response. The calibrated finite element models were used to determine relatively minor modifications to the support deck that could be implemented as part of the initial installation.

The Tantawan Explorer has been in service in the Gulf of Thailand for several years. The compressor systems have been "silky smooth" according to a customer spokesman.

Beta Machinery Analysis has developed a balancing procedure that allows balance to be improved without the expense and downtime associated with normal trial weight balancing. This procedure offers quick, efficient balancing of any type of equipment where minimizing downtime and maximizing safety are key concerns.

It solves a long-standing problem in the Pulp & Paper industry. Paper machines typically have 40-50 dryer cans - slowly rotating, but massively large cylinders that can generate large forces. Consequently, dryer can balance plays an important role in paper machine reliability and profitability.

Dryer cans commonly weigh in the range of 18,000 to 30,000 pounds. Driving and supporting these components dictates dryer section frame design. Dynamic forces developed by these rotating pressure vessels, normally dominated by unbalance, tend to determine bearing and geartrain life, lubrication needs and frame/support viability.

The matter has become more significant with the general trend to increase paper speed for increased production. Considering the inherent series production nature of a paper machine, good balance of all 40 to 50 dryer cans is a critical issue for reliability and profit.

Poor residual unbalance levels are most often due to:

- machine speed increases
- failure to maintain or re-balance dryers after correction weights are lost or after head changes
- misapplied weights on dryers pre-dating correct dynamic balancing.

Dryer unbalance can be compounded by condensate flooding or poor draining. This can also have a major impact on bearing life. Pressure differentials should be increased to evacuate excess condensate when evaluating balance and the results compared to previous normal levels.

Removing the dryers for balancing is prohibitive. It is possible to remove drive gears, install a temporary drive means and then balance a dryer during a machine shutdown, but this procedure is very time consuming and expensive.

Working closely with a client, Beta has developed a method of determining balance correction with the paper machine in normal operation and without the need for trial weights.

In this case, because of speed increases in the last decade, residual unbalance had become a visible problem on several dryers in this paper machine. Bearing and gear maintenance needs were increasing and the framework was noticeably flexing. A desire for a further speed increase was complicated due to the dryer rotational frequency approaching a frame resonance frequency.

Vibration characteristics of the 22 upper dryers (higher in the framework and, therefore, more problematic) were analyzed exhaustively. A major issue is determining what portion of the 1X response is due to unbalance on this dryer and what portion is due to cross-talk from adjacent rolls. Another aspect is cycling (long term variation) of the vibration.

Vibration was trended, profiled and analyzed over time to help determine cycling and cross-talk effects. A combination of speed trials, laboratory tests and mechanical natural frequency analysis was undertaken to detail the balance response and instrument and mechanical phase lag behavior over the operating speed range.

The first correction weights were installed during a routine shutdown in early 2001. Due to newness of the technique, it was decided to attempt to correct the unbalance of the two worst dryer cans by 50% with the first correction weight installation.

Measurements following the installation of these weights showed that both were improved by 51%. On the first dryer, the weight was within 5 degrees of the correct location. For the second dryer the weight was 29 degrees from the correct location, mainly due to mounting restrictions on the inside of the head.

Based on this success, the client has since corrected two further dryers with full recommended first weight installation with no further data being taken or analyzed. The results were similar.

The new technique was recently used to safely and quickly balance a dryer can on another paper machine during a routine shutdown. With an extreme level of 85 mils of vibration, no margin existed for worsening the vibration with the correction weights. This technique allowed the vibration to be improved 45% versus a target 50% on the first run. The final installed weights improved the residual unbalance by 80%.

This procedure allows safe and efficient balancing of any equipment where downtime and production loss costs are high. Examples would include high priority blowers and process fans.

Interesting Torsional

Introduction

BMA was hired to measure the torsional vibrations on a centrifugal compressor driven by variable frequency drive motor. The unit had been modified from its original 450 HP motor to a 600 HP motor. Upon startup, the coupling failed (broken bolts) several times; within two weeks for both failures. The coupling was a flexible disk type with a spacer. The compressor manufacturer had done a torsional analysis and had noted that the torsional natural frequency was in the 40 Hz range. They also noted a possible excitation of that natural frequency by a 12th order harmonic from the VFD. In our tests we used a digital strain gauge telemetry system to measure the actual torque carried by the coupling spacer. The strain gauge system was used, because it was felt important to measure the mean torque as well as the vibratory torque.

Along with analysts from Beta, the test was attended by a representative of the compressor manufacturer and of the variable frequency drive manufacturer. It was expected by all, that some harmonic from the VFD was exciting the torsional natural frequency and damaging the coupling. That expectation was dashed by the data that was measured.

Findings

The fundamental torsional natural frequency did in fact show up in the run up of the unit. It was found to be at 42.5 Hz, which was slightly higher than predicted by the modelling. However, what was not expected was that the component was present in the torque spectrum from almost zero RPM up to full speed of 3600 RPM. The amplitude did increase temporarily as the 6x, 3x, and 1x shaft speeds reached 42.5 Hz. When the compressor was in the vicinity of 3000 RPM, the compressor was in surge, and we were unable to capture peak measurements as the instrumentation was overloaded by the amplitude of the torsional vibration at 42.5 Hz. All we can say for sure is that the amplitude was more than 13,000 in-lb to overload the instrumentation, and was probably much higher. With that vibratory torque, and the mean torque measured, we know that the coupling was severely overloaded during the surge.

But what excited the fundamental torsional natural frequency throughout most of the operating speed range? The answer was flow induced pulsation caused by vortex shedding of the flow past a manway just upstream of the compressor suction. This is the first case, that we are aware of, where the

excitation of a torsional natural frequency was flow induced.

Also, of note is the fact that the manway did not have a resonant sidebranch to amplify the pulsations, but we suspect that the pipe is acoustically resonant at or near the same frequency as the torsional NF. This is unusual, since there is usually enough damping in the pipe with mean flow to damp out any acoustical resonance. A dead leg is usually involved because there is no flow and hence no damping.

Solutions

- 1) Modify the control systems to detect and avoid surge during startup and operation.
- 2) Build a plug for the manway to eliminate the source of vortex shedding.
- 3) Size the coupling to accommodate the measured mean and vibratory torques under normal operating conditions.

Training

Beta Machinery Analysis has joined with Dresser-Rand to offer the following training opportunities.

If you would like further information or wish to attend any number of these courses please contact our Calgary (1-800-561-2382) or Olathe (1-888-391-2382) office.

Basic Engine/Compressor Analysis (IEA-104) April 23 - 26, 2001 - Dresser-Rand Training Facility, Houston, TX.

This 4-day course is designed for operators and new analysts and will introduce economics and risk assessment as an integral part of the analysis process.

Cost: \$925USD Must be registered by April 9

Intermediate Engine/Compressor Analysis (IEA-204) June 4 - 7, 2001 - Dresser-Rand Training Facility, Houston, TX.

This course is designed for the more-experienced analysts. The emphasis will be on economics and risk management as an integral part of the analysis process. Topics introduced in the basic course will be continued and extended.

Cost: \$925USD Must be registered by May 18

Reciprocating Compressor Reliability & Condition Monitoring (RCR-214), June 19 - 22, 2001 - Baton Rouge, LA

A four-day program for analysts, rotating equipment engineers, and maintenance technicians who are responsible for de-bottlenecking compressor installations and increasing equipment reliability. This course combines proven reliability related issues and OEM equipment upgrades with condition monitoring experience to offer a comprehensive learning experience. Major wear-item maintenance practices are outlined, followed with specific analysis descriptions utilizing case studies, analyzer plots and graphics to illustrate failure modes and corrective actions.

Pulsation Vibration, May 2 a.m., 2001. Understand how acoustical and mechanical analysis gives you smooth startups and trouble-free operation. Due to demand we have added this extra training opportunity.

We plan to schedule the following, no charge, seminars for the final quarter of 2001W

Pulsation Vibration

Balancing Compressor Design with Risk

Torque Talk

An introduction to gas turbines and centrifugal compressors

News & Notes

Did you know...

Beta Machinery Analysis does all the Canadian repair and service on RECIP-TRAPS, DATA-TRAPS and BETA-TRAPS. If you require work done on your traps call Ken Ng in our Calgary office, 1-800-561-2382 or Cam Dowler at Dynalco Controls 954-739-4300.

Take a look...

Dr. Bryan Long, President of Beta Machinery Analysis, was a presenter at the 2000 RECIP-TRAP Users' Group for Dynalco Controls in Houston. They have posted his paper on their website at www.dynalco.com

Beta was there...

- with the API Task Force at API Headquarters in Washington, DC to work on the next edition of API 674 Plunger Pumps.
- at the PMACC (Power Machinery Compression Conference) held in Austin in March
- at the Floating Production Systems Conference held in Houston in February.
- at the Society of Tribologists and Lubrication Engineers (STLE) annual meeting and exhibition in San Antonio in February. Their main theme was "Condition Monitoring".

Beta Machinery Analysis has completed an alliance agreement with The Hanover Company, covering the provision of BMA design services for equipment supplied by Hanover. The agreement will extend to all Hanover fabrication divisions, namely: Hanover Maintech; Hanover Davis; Hanover DR; Hanover South Loop; Collicut Hanover; Hanover Turnkey & Treating.

Our website is still a work in progress. Please drop in and pass on your comments and suggestions.

www.betamachinery.com

New look for the Beta Bulletin. It's bigger and better. Are there topics you would like us to cover? Please contact us at info@betamachinery.com

Drop in and see us at the Beta Booth:
Eastern Gas Compression Roundtable,
May 8 - 10, Robert Morris College,
Pennsylvania
Peace Region Petroleum Show,
May 16, 17, Grande Prairie, Alberta

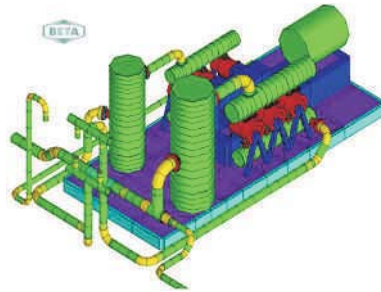
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Beta Services FEA: Finite Element Analysis

Our experience shows that poor mechanical design accounts for over 50% of the vibration problems encountered.

What is the benefit of the analysis?

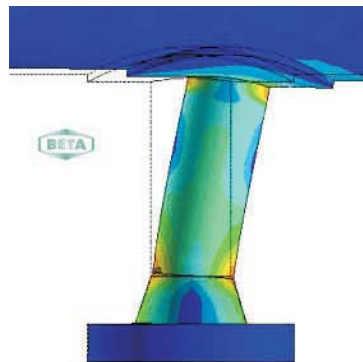
A thorough mechanical analysis is extremely important in reducing the risk of costly repairs and downtime. We can examine the system at the design stage, recommend a solution to an existing problem, or find the root cause of a failure.



How much analysis should be done?

One of our engineers can recommend the best analysis approach for your project. We can tailor the complexity and detail of our analysis to suit your application, budget, and schedule.

The tools used by our experienced analysis team include: ANSYS, Caesar II, and in-house software.

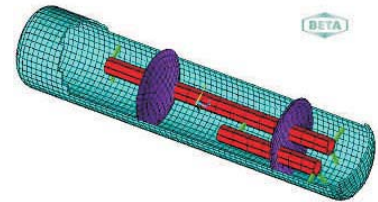


Types of Finite Element Analysis

- Mechanical Natural Frequency and Mode Shape Analysis
- Harmonic Forced Response Analysis
- Operating deflected shape
- Vibration and stress levels
- AISC structural code checks
- Thermal Analysis
- Torsional Analysis

Our Experience

- Reciprocating Compressors
- Centrifugal Compressors
- Crew Compressors
- Centrifugal Pumps
- Plunger Pumps
- Engines
- Motors
- Shafts
- Fans
- Piping Systems
- Coolers
- Vessels and Internals
- Skids
- Foundations
- Piles
- Soils
- Support Structures
- Platforms
- Decks



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