Technical Paper

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Integrity of Pulsation Dampeners in Liquid Systems

Note: This paper has been revised from the original to add two sentences to page 9, heading 5, last paragraph, regarding future installations.

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Summary

This paper demonstrates the real need for a better system to understand and monitor the integrity of gas charged pulsation dampeners and examines the idea of using pulsation monitoring to monitor gas charged dampener integrity during regular reciprocating pump operation. The examination looks at a particular new installation on an offshore platform for Shell Malaysia.
The difficulty and risk in maintaining a safe pump system with these dampeners is magnified in offshore and un-manned equipment operations. Until better options appear on the market to address these important issues, pulsation monitoring is a technique that can be used to monitor dampener integrity. However, when using pulsation as the monitoring strategy several important considerations must be taken into account.

1 Introduction

Reciprocating pumps emit pulsations into the attached piping systems causing potentially dangerous unbalanced shaking forces, poor valve dynamics, high maintenance costs, and reduced flow. It is well known that gas charged elastomeric bladder or diaphragm pulsation dampeners can be used to effectively reduce the risks of these pulsation induced problems. Gas charged dampeners are relatively compact in size, and are easy to install when compared with maintenance free liquid filled options which tend to be large and more expensive to fabricate. However, gas charged dampeners come with some drawbacks which include:

- Several failure modes: loss of gas charge, incorrect gas charge, elastomeric rupture, ineffective location
- Must include maintenance activity to inspect the integrity of the elastomeric component
- Must ensure the appropriate charge gas volume/mass in the cavity for optimum pulsation control
- The potential for the dampener itself to become a vibration problem due to its branch connection being a heavy cantilevered mass having low mechanical natural frequencies
- Ability to control pulsation only at a narrow range of pressure/flow conditions, and pump speeds
- The lack of indication that the dampener is performing as it should.

These drawbacks are common issues for many operators worldwide[1] including Shell Malaysia. In a recent brownfield upgrade pump installation, Shell requested that the new pumps include a monitoring system to indicate when the gas charged dampener has failed. We werecontracted to include this study with the pulsation analysis being performed as per API 674. The hypothesis of the monitoring study was simple: when the dampener fails pulsations increase, an alarm is then triggered indicating a dampener failure.

The test of this hypothesis is presented in the following case study of a Shell brownfield upgrade. The case provides background of Shell experiences, the pulsation system model piping design, examines the complications that arise in a real installation, and the challenges to overcome with variable speed pump operation.

2 Background

Shell Malaysia has numerous reciprocating pumps for glycol and hydrocarbon condensate duties on both manned and un-manned offshore platforms. A majority of the older installations have reciprocating pumps equipped with bladder type pulsation dampeners. There have been numerous technical integrity issues related with the pulsation dampener losing pre-charge frequently, cases with the bladder material rupturing prematurely, and many cases of a notable increase in the vibration of the pump pipework leading to a failure and loss of containment.

With no form of indication available to ascertain the pre-charge pressure, it is difficult if not impossible to determine if the bladder, and/or bladder pressure is intact and holding. The only way to tell if the pulsation dampener is not performing as intended and has lost pre-charge is visual inspection of pipework. When the dampener has lost its pre-charge, the pipe work rattling and high vibration indicates some flaw in the working of the dampener. Under these circumstances the equipment has to be shutdown to manually inspect the dampener, as this has a direct impact on the reliability and downtime of the equipment.

The reciprocating pumps at the Shell facility are not equipped with on-line condition monitoring and the maintenance philosophy revolves around periodic off-line vibration condition monitoring typically carried out using hand held instrument at three monthly intervals. For unmanned platforms the increase in vibrations are detected when the pump pipework vibration has increased substantially on account of loss of pre-charge or the bladder giving away, presenting a high risk threat for operations.

The bladder in the dampener is very sensitive to changes in gas volume. As the line pressure changes, the volume of gas in the bladder changes, thus altering the system performance. The effectiveness of the pulsation dampeners can be reduced by bladder stiffness, bladder permeability, restriction of bladder expansion and contraction by dampener internals and degradation of performance due to large variations in line pressure, making the prediction of dampener performance complicated.

Technical integrity issues with the bladder material rupturing prematurely also surface when technicians charge the pulsation dampeners to quickly, leading to low temperatures at the elastomer interface and cracks propagating through the material. This has the effect of ultimately causing premature failure of the bladder material within a few charges.

Loss of containment through excessive pipe vibration and dampener failure, and the resulting impact on reliability statistics provided the motivation to address some of the issues described above. An opportunity to monitor the technical integrity of pulsation dampeners arose through brownfield project of F13 condensate transfer pumps (Triplex –double diaphragm type) to be installed on the existing E11 PB platform.

3 Attempts to Address the Problem

3.1 Type of Dampener

In order to address the pulsation dampener integrity issues, a change in the type of dampener from bladder type to the acoustic liquid filled type was considered. This approach was successful only on the Greenfield projects. For the brownfield applications this approach met with a limited success considering the fact that space and cost of the liquid filled dampener is much higher than an equivalent gas filled dampener.

The existing piping arrangement is often congested, particularly for offshore facilities, hence the option of installing a liquid filled dampener is effectively ruled out. Moreover most of the pumps within Shell facility are slow speed with low frequency. Thus this approach was not effective in resolving the brownfield installations.

Metallic bellows type dampeners were next considered for cases where the bladder failed prematurely or failed to hold the pre-charge with the elastomeric element slipping off. This approach did provide some amount of success especially with the high temperature glycol service where the fluid temperature is around 120 deg C. The high temperature for the glycol service led to the pre-mature failures of the bladder elastomeric element and cases where the bladder lost its pre-charge within a few days of operation.

Despite resolving some of the integrity issues the problem of not being able to detect the condition of pre-charge pressure for nitrogen remained.

3.2 Monitoring the Dampener Itself

Manufacturers of pulsation dampeners were requested to provide some form of indication on the pulsation dampener for ascertaining the pre-charge of nitrogen. Some of the pulsation dampeners complied with this requirement by providing a T-connection with one end of the T connected to a pressure gauge. However such indication is purely local and is of value only at manned platforms. For the unmanned platforms the issue of pre-charge pressure uncertainty remained.

3.3 Monitoring Vibrations

With appropriate signal conditioning, accelerometers could be used to measure the low frequency and high frequency vibration. Accelerometers mounted on the pump manifolds serve this purpose. The acceleration data can then be used to identify issues with plungers/control rods or valves. However, vibration on the pump piping is generally due to the unbalanced forces in the piping from pulsation, as such measuring vibration would be an indirect method of gauging pulsation. So why not measure pulsation directly?

3.4 Monitoring Pulsations

Based on the limited success with the above approaches, Our company was engaged to work with a manufacturer to provide a solution for triplex pumps to be installed on an un-manned Shell facility. The objective of this exercise was to design an effective and well controlled pulsation system, and at the same time develop a monitoring system which would be capable of detecting the condition of pulsation dampeners and alert operations for any abnormal behavior in the system. It is also to provide some form of assurance to predict the behavior of the dampeners under dynamic variations in the system pressure. F13 condensate transfer pumps were the subject of this approach.

4 Pulsation Modeling

4.1 Dampener Modeling Approach

When a pulsation dampener loses charge, or fails, pulsation will increase. The initial monitoring concept was when pulsation levels increase past a limit, send an alarm to the control system indicating to operations that the dampener has failed. The concept is simple, but the reality in this case was actually very complicated.

4.1.1 The System

The pump system under analysis was for two triplex diaphragm condensate pumps, operating in parallel across a variable speed range of 37-120 rpm (pump speed). The pump flow conditions were forecasted from reservoir data and had expected yearly changes in flow and differential pressures from years 2012 up to 2020.

The large speed range of these pumps would present significant challenges to the activities of this project.

4.1.2 The Pulsation Model

A pulsation model was created for the initially designed system including the two pumps, off-skid rack piping between the pump skid and inlet contactor vessel, and the main discharge export manifold using our company’s proprietary, non-linear, fluid dynamic modeling software. See Figures 1 and 2 for images of the suction and discharge system pulsation models. The model input to the piping system involves the calculation of pump performance and the actual pressure profile of the fluid versus time of each fluid end of the pump. Each fluid end has its own input into the piping system per rotation of the crankshaft, since each end travels to outer dead center 120˚ out of phase with the other. This creates the tendency of a triplex pump to have the highest pulsation input at the third order (3X – 3 events per rotation), and multiples of 3, into the piping. This is typically referred to as plunger passing frequency (PPF). So if you collect frequency domain pulsation or vibration on piping around a triplex pump, you should see excitation at 3 times rotational speed of the pump (or PPF) and multiples thereof.

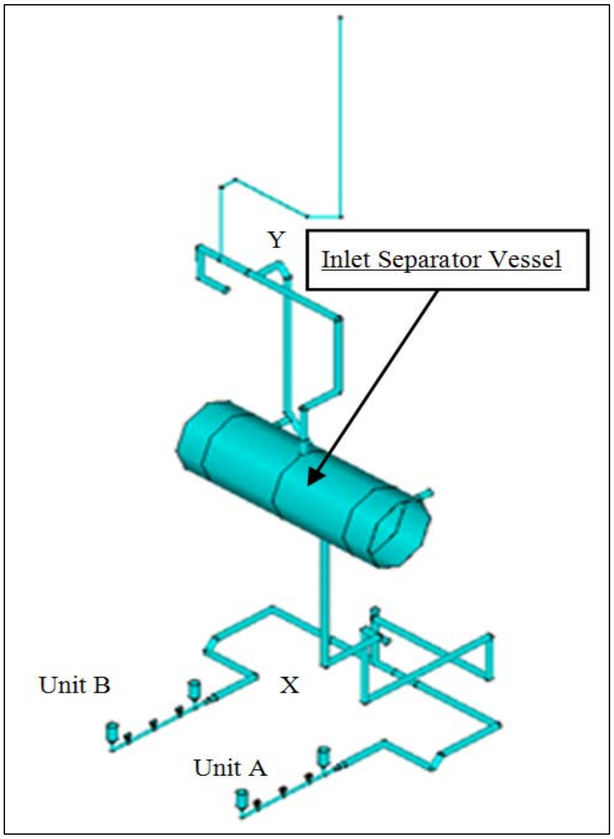

Figure 1: Suction Piping Model

The pulsation analysis was conducted with the piping system and dampeners as proposed. Results were compared to API 674 3rd Edition guidelines and our company's unbalanced shaking force guidelines. The initial results found that there were pulsation guideline violations at several locations within the piping at PPF and twice PPF, and high unbalanced forces were predicted in the suction header and discharge PSV and bypass lines, all at various pump speeds. Cavitation was also predicted to occur in the suction system. Modifications were required.

The pump OEM bid for this project included the preliminary sizing of a pulsation dampener for the suction and discharge side. The dampener was sized for a given volume using standard rule of thumb calculations based on the concept of acceleration head. Dynamic pressure or pressure pulsation in pump systems has historically been referred to as acceleration head. A common misconception is that sizing pulsation control devices for pumps using acceleration head sizing calculations is equal to an API 674 pulsation study. This is not the case. Calculation of acceleration head is a technique whereby the pressure fluctuation is estimated by simplifying assumptions and empirical techniques. Acceleration head calculations cannot take into account acoustical resonances in a piping system. Acoustical resonances can result in very high pressure pulsations because of the low damping and high amplification of pulsations at resonance. A computer model that calculates the acoustical properties of the piping system as well as non-linear pressure and flow fluctuations is required to accurately determine the suction system pressure pulsations. Acceleration head calculations are not as effective at characterizing pressure pulsations as a pulsation computer model. This is illustrated by the initial results of the pulsation analysis as originally designed, stated earlier.

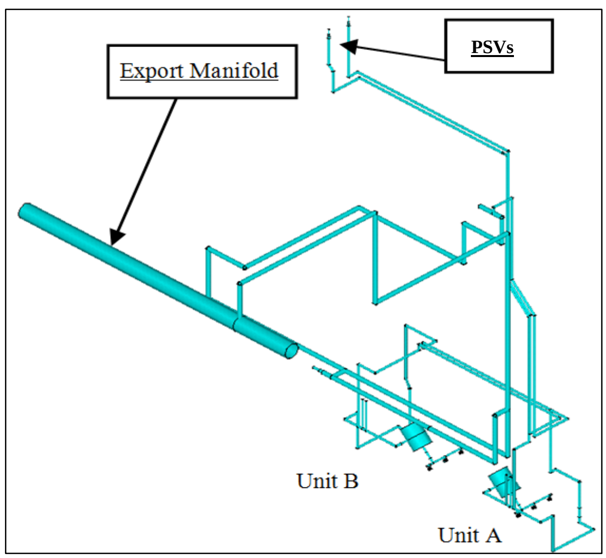

Figure 2: Discharge Piping Model

The suction system with the initial designed acoustic dampener had several areas of acoustical resonance causing cavitation and high unbalanced shaking forces. Several modifications were attempted including a larger volume pulsation dampener, maintenance free dampeners, and piping layout changes. The optimum solution included a second pulsation dampener at the blind end of the suction manifold, and modification of the piping such that the manifold connecting the 2 units was of a symmetrical design.

The wide speed range of this pump, combined with acoustical resonances within the suction piping system required a 2nd pulsation dampener at the blind end of the suction manifold. Two dampeners on one manifold is not a common sight for many pump systems. As such, some description as to why it was required is necessary.

Gas charged pulsation dampeners work upon the principal that pressure surges will be absorbed by the damping of the gas charge within the dampener. When a pump is operating at a fixed speed the pulsation dampener location is an important aspect of pulsation control for pumps. Diaphragm, or bladder type dampeners are most effective when placed at a location of maximum pulsation, known as a pressure “anti-node”. If the dampener is placed at a “node” location, (where there are low pulsations in the piping standing pressure wave), the dampener will do nothing at all. This is where the problem lies in variable speed installations. The locations of nodes and anti-nodes in the piping change with speed. This means if you have a pulsation dampener at a fixed location, it will be effective for a narrow range of speeds, and ineffective at most of the other speeds of the pump. This was the case for this pump system.

One of the ways to increase the effective speed range of the dampening system is to add another pulsation dampener at a different location. In this case the second dampener was installed at the blind end of the suction manifold for a few reasons. A common phenomenon when placing a dampener near the inlet or outlet of the manifold is the creation of a quarter wave resonance between the dampener and capped end of the manifold. This quarter wave resonance can create high pulsation levels within the manifold piping which interfere with pump valve opening and closing events, and also create high pulsation induced unbalanced forces on the manifold. One effective way of reducing this quarter wave resonance is to install a second dampener at the capped end, which has the added benefit of increasing the effective speeds that the pulsation dampening system can handle.

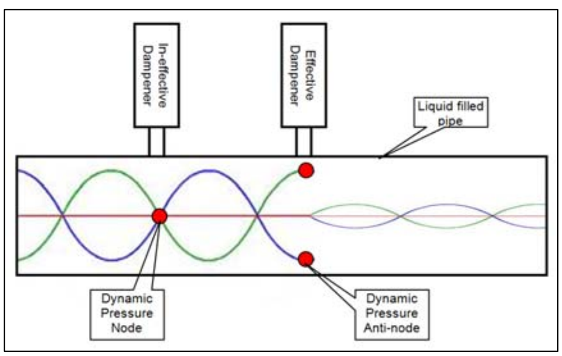

Figure 3: Simplified Example of Dampener Location

The discharge system utilized a maintenance free liquid filled dampener at the manifold outlet. Even with the maintenance free dampener, quarter wave resonances were found in the bypass piping for both units, and pulsation forces within the relief valve piping exceeded guideline. Modifications included shortening the bypass piping by relocating the valves, and adding extra clamp supports to the relief valve piping to withstand the marginal forces.

4.1.3 Cases for Investigation

Since two gas charged dampeners were required for the suction system, the investigation into the dampener integrity control system involved 4 pulsation cases:
CASE 1: Both dampeners functioning
CASE 2: Manifold inlet dampener fails
CASE 3: Manifold blind end dampener fails
CASE 4: Both dampeners fail
Once an acceptable pulsation solution was found for the suction system, a simulation of each case was conducted to determine how best to setup the dampener integrity monitoring system. A monitoring system for the discharge was not needed since gas charged dampeners were not used.

4.1.4 The Results

A detailed study of pulsation levels in the piping system throughout the speed range was completed at locations where a clear difference could be seen in pulsation levels to determine the state of the dampener. Each case was simulated by removing the gas volume within the dampener.

The results were found to be highly dependent on speed of the pump. Two locations were better for finding a significant difference in pulsation levels between failure cases. The locations are highlighted in Figure 4. The pulsation levels predicted at location 1 provide better indications of failure of the manifold inlet dampener. Pulsation levels predicted at location 2 provide better indications of failure of the manifold blind end dampener.

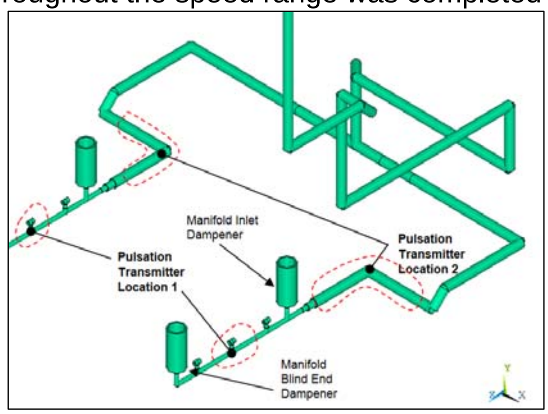

Figure 4: Suction Manifold Dampener and Pulsation Transmitter Location

Figure 5 shows the pulsation amplitudes of each of the 4 cases throughout the speed range for transmitter location 1. Pulsation amplitude is plotted verses pump speed (rpm) for each of the cases. It can be observed from Figure 5 that monitoring for failure of the stabilizers for cases 3 and 4 is best between 75-100rpm. The relative pulsation amplitude between Case 1 and cases 3 and 4

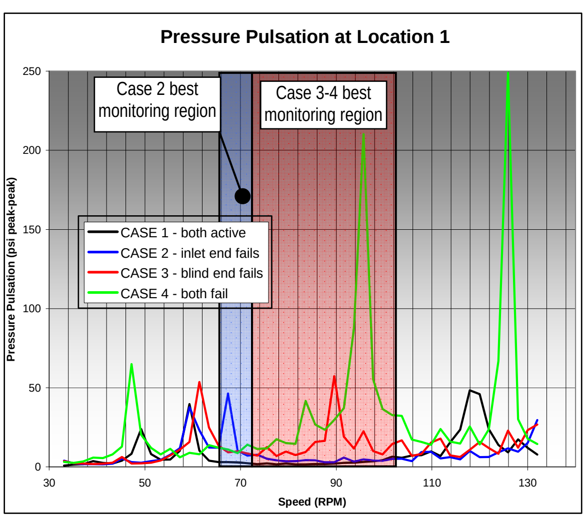

Figure 5: Location 1 Pulsation Response of Each Case

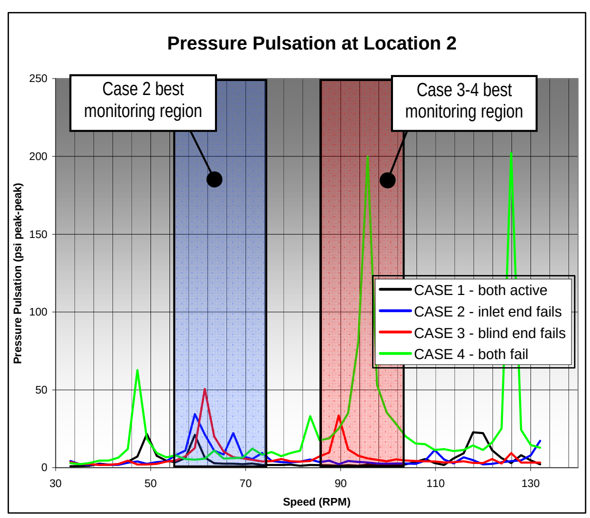

Figure 6: Location 2 Pulsation Response of Each Case

provides a margin of difference for a control system to monitor. The highest relative amplitude difference between cases 1 and 2 occurs at the narrow range of 63-69rpm. Case 2 pulsation levels are marginally higher than Case 1 from 70-100rpm but not by a significant difference. Both regions are highlighted with shaded boxes.

Similar to Figure 5, Figure 6 shows the pulsation amplitudes of each of the 4 cases throughout the speed range for transmitter location 2. It can be noted that the monitoring region (in terms of speed range) for case 2 is wider for transmitter location 2, than for location 1. Showing that there is a slight benefit for Case 2 detection using location 2 over location 1.

The pulsation induced unbalanced forces for each failure case in the long vertical suction line between the inlet separator and suction header splitting to each pump (see line X-Y in Figure 1) is shown in Figure 7. Case 4 of both dampeners failing can result in nearly 1900 lbs pk-pk force shaking the pipe. The next worst case is Case 3 which results in nearly 600 lbs pk-pk in the same line.

5 Checking Integrity at a Specific Speed

The analysis determined that dampener integrity was best checked using pulsation at specific pump speed ranges. The pump OEM and Shell stipulated they only wanted to measure and monitor at one location on the pipe, so it was reasoned that measuring at location 1 would have the best chance of detecting a dampener failure. The reason being that location 1 has the widest speed range to trigger an alarm, and if an alarm is triggered, both dampeners would require inspection.

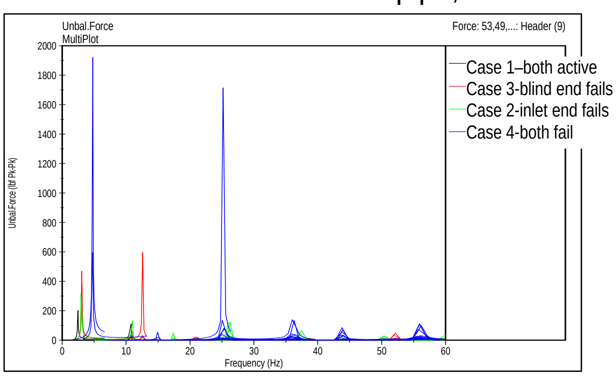

Figure 7: Pulsation induce unbalanced shaking force of Line X-Y for each case

These results showed that operations will periodically need to speed up the pump to between 60-100rpm to detect dampener failures, especially if the pump has been operating at a lower speed for an extended period of time.

This analysis was completed for each of the different projected loading scenarios (pressure, flow) for future years of operation. The analysis profiles for each different year proved to be very similar, and the data shown above is representative of operation from year 2012 to year 2020.

An additional assumption required for this model is that only one of the pumps is running at the time of the integrity check. Since these machines are variable speed, in theory any speed the sister unit is operating at affects the pulsations of the system which, in turn, changes the pulsation profiles shown earlier. The sensitivity of the pulsation profile at each measurement location to the sister unit was tested for this system and found to be of low consequence. For any future installations this assumption needs further investigation on a case by case basis.

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6 Pulsation Monitoring System

The most common pressure monitoring systems measure mean pressure in the line. Many of these sensors have high sampling rates capable of detecting dynamic pressure changes such as pulsation. The problem is that they are a DC coupled signal, which provides a voltage proportional to static and dynamic pressure.. This makes for difficult pulsation monitoring in systems with static pressure swings. To measure pulsation levels in the piping using DC coupled sensors, a monitoring system would constantly need to subtract the mean pressure of the system out to understand pulsation changes. To compound the matter, if you wanted to set up an alarm to trigger a dampener failure (when pulsations go up), the alarm would have to float with the mean pressure as it changed as well. This is not an ideal monitoring philosophy for a system with known pressure swings.

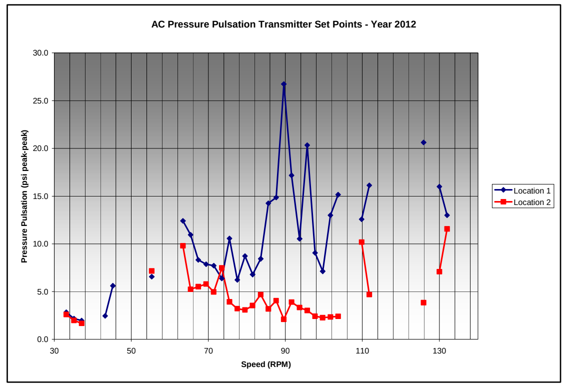

Figure 8: Pulsation Transmitter Alarm Set Points for OperatingYear 2012[2]

All these difficulties are removed if the pulsation is monitored using AC coupled pressure transducers. AC pressure transducers will provide a voltage proportional to dynamic portion of the pressure, and remain independent of static line pressure swings. In other words they provide a direct reading of pulsation for that location, and can be compared to alarm levels more easily.

However, given that the pulsation amplitudes change drastically with speed, a single alarm set point was not possible for this variable speed system. If a single alarm set point were chosen, it could be effective at the speed for which it was set, or it could give excessive false alarms, or no alarms at all depending on the setting. As a result, an alarm set point which changed with speed was required. Figure 8 shows alarm set points for various pump speeds for the operating year 2012 for each pulsation measurement location.

Pulsation alarm set points were provided for speeds where the failed dampener case produced pulsation levels higher than during normal intact dampener operation. The alarm set points shown are for 90% of the failed pulsation value for that speed. For speeds where pulsation levels do not effectively determine a failed dampener, no alarm set point is given. This is because pulsation at those speeds cannot be used to determine the state of dampener integrity.

7 Practical Operational and Maintenance Limitations

For this installation, pump speed is controlled with respect to the supply tank levels. So speeding up the pump to check for dampener integrity can prove difficult, especially at times of low tank volume.

As such special maintenance planning is required to check dampener integrity alarms at periodic intervals. This will involve changing pump speed briefly, 5 to 15 minutes, to the specified range to get an indication if pulsation dampeners are intact. Due to the difficulty of accurately predicting each failure case with one pulsation sensor location, both suction dampeners will need to be checked if pulsation alarms are triggered.

Additionally other upset conditions such as failed valving could also trigger the monitoring system, and if dampeners are found intact, valves should also be inspected.

8 Conclusion

This paper demonstrates the real need for a better system to understand and monitor the integrity of gas charged pulsation dampeners. The difficulty and risk in maintaining a safe pump system with these dampeners is magnified in offshore and un-manned equipment operations. Until better options appear on the market to address these important issues, pulsation monitoring is a technique that can be used to monitor dampener integrity.

When using pulsation as the monitoring strategy the following considerations must be understood:

1. Every system will be different, there is no blanket solution.
2. The system design is challenging and requires a pulsation piping model
3. Variable speed and dual dampeners, will add additional complexity to the system. Compromise may be necessary.
4. Multiple variable speed units add complexity to the monitoring. The monitoring needs to consider the speed and input from the additional pumps on the system.
5. AC pressure transducers are required to monitor pulsation levels.
6. Fixed speed applications would be much easier to perform this style of monitoring. One sensor, at a specific (anti-node) location will likely suffice, with a single alarm set point available.

Bibliographic details

[1] CompressorTech2, Poor Pump Design Considerations Can Limit Operations, page 58, April 2012
[2] Pulsation Analysis Report for Shell F13 Condensate Transfer Pumps, March 2012

link to www.BetaMachinery.com