ORBITAL Case Study

VE Technology® Helical Strakes

Vortex induced vibration testing of Thermowells & Sample Probes

Background

Orbital Gas Systems, in partnership with Daily Thermetrics, conducted flow testing on May 1, 2017 at a respected North American independent metering research facility. This first-of-its-kind test proved the effects of vortex-induced-vibration on traditional and helical probe geometries in a typical high-pressure, high-velocity pipeline environment. This testing was commissioned to validate thousands of hours of research, whitepapers, CFD models and millions of hours of operational service over the past 12 years by tracking data and performance in a real-time, real-world, setting.

Test Facilities

The probes were tested in a high-pressure recirculation test loop used to simulate flowing conditions in natural gas transmission pipelines using distribution-quality natural gas as the flowing medium. The testing was carried out at a range of velocities/flowrates within both a 6" and 12" pipeline at a pressure of ~950psi.

Thermowell Test Articles

A helical strake thermowell and a typical "ASME"* straight-shank thermowell were monitored at a series of flow rates where vortex shedding was expected to cause resonant vibrations for the ASME thermowell.

All the thermowells were fabricated from 316L stainless steel with ANSI B16.5 2" 600# raised-face flanges. Each thermowell was mounted to a standoff perpendicular to the pipe axis. The standoffs and thermowell lengths used were fairly typical lengths, chosen to measure from the centerline of the pipe and expected to produce resonant vibration at various flow velocities possible within the test facility flow range.

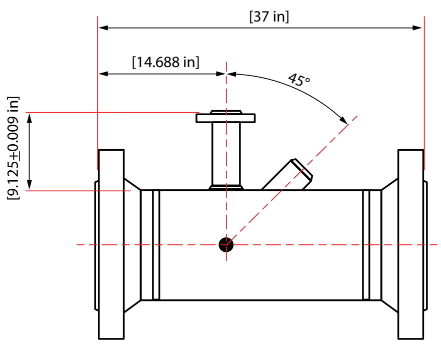


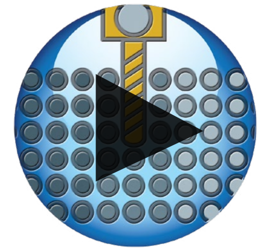
Figure 1- pipe spool. Thermowell mounted in the vertical nozzle with a high speed camera attached on the downstream latrolet

As shown in Figure 1, the test spools were installed in straight pipe runs separating the thermowells along the pipe axis by more than 15 pipe diameters. This spacing allowed the flow disturbances created by each thermowell to dissipate and provided distance for the turbulent flow to fully re-develop between thermowells. Directly upstream of the test section, over 100 nominal diameters of 12-inch pipe provided a fully-developed flow.

Sensors and Data Acquisition

To quantify the thermowell vibrations an accelerometer (at the tip) and strain gauges (at the flange/shaft interface) were incorporated into each thermowell.

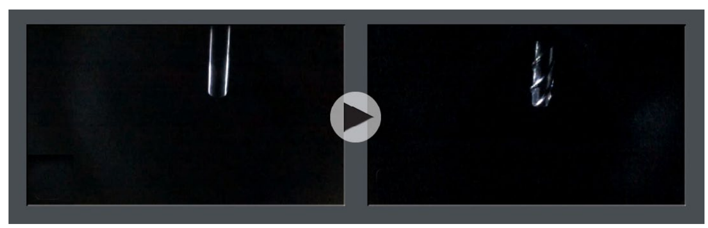
Figure 2 - Thermowells used to 'sample' from the centerline within the 12" pipeline



Video 1 - Entire test video recorded at 960fps, playback at ~25fps

Results – 12ft/s

The first point of interest was at ~12ft/s velocity. Velocities of this magnitude coincided with a region of concern (based on calculations according to ASME PTC 19.3-2016) relating to potential in-line vibration of the ASME thermowell with a wake frequency (fs) within the lock-in zone of the natural frequency (fnc) (0.4 fnc < fs < 0.6 fnc).

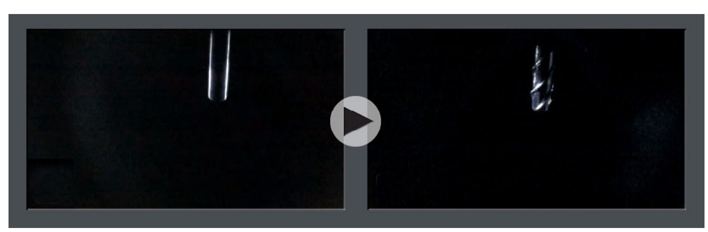


Video 2 - ASME thermowell and helical strake video, 12ft/s.

As is shown in Video 2, the ASME thermowell demonstrated clear in-line vibration and had entered a resonance condition whereas the helical strake thermowell had zero visual vibration.

Results – 24ft/s

This velocity was chosen to achieve an approximate 1:1 ratio between natural and wake frequency for the thermowell geometry (fs = fnc).



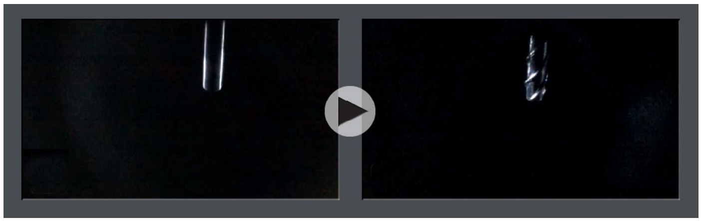
Video 3 - ASME, 24ft/s. & Helix, 24ft/s. (consider the vibration is 90Hz, and therefore there are 90 complete cycles per second)

Video 3 clearly shows that the primary oscillation is now transverse to the flow (as expected) for the ASME thermowell. The transverse displacements were of the order of magnitude of 0.5" whereas the total displacement of the helix thermowell was of the order of thousandths of an inch.

*For patent information for all Orbital technology, please visit www.orbitalgas.com/patents.

Results – 30ft/s

At ~30ft/s the ASME thermowell has reached a condition where fs > 1.2 fnc and so the thermowell is outside the lock-in zone and should theoretically be a safe design. The helical thermowell (due to its higher natural frequency) is now well within the potential lock-in zone of 0.8 fnc < fs < 1.2 fnc.



Video 4 - ASME, 30ft/s. & Helix, 30ft/s.

The ASME thermowell is again seen to vibrate (Video 4) but with a reduced magnitude which is as expected due to falling outside of the natural frequency of the thermowell. Although within the lock-in region for the helix thermowell, there continues to be no Vortex induced Vibration.

Results – Strain Gauges

In support of the visual files, the strain gauge data was also examined. Although there was evidence of drift due to temperature effects and therefore a review of the strain amplitude was not possible (i.e. the y-axis in Figure 3 should be ignored), the differences in the magnitudes of the strain, the oscillations and the associated frequencies can be seen in Figure 3, which shows an example of the periodic nature of the strains measured in the 12-inch thermowells at 80% flow capacity (~24ft/s) – this strain data shows a strong correlation with the visual recordings.

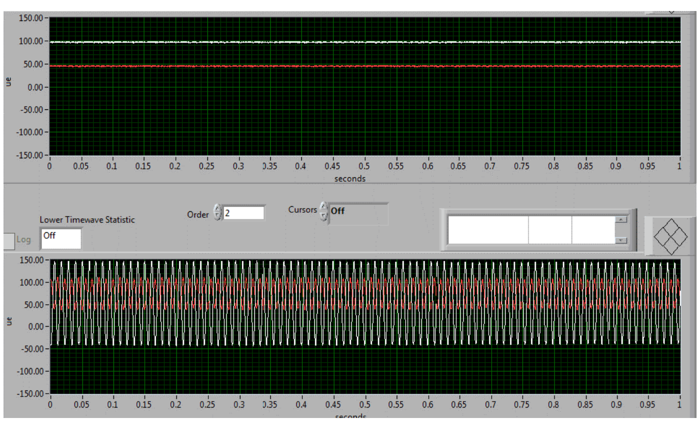


Figure 3. Measurements by the Strain Gauges in the 12-inch Thermowells at 24 ft/s

The top graph in Figure 3 shows the transverse (white) and in-line (red) strain measurements within the helical strake thermowell over a period of one second. The lower plot shows the strain measurements taken within the ASME straight thermowell at the same time. Both plots are shown to the same scale to demonstrate the differences in cyclic strain magnitudes at the thermowell roots. The offsets from zero are due to temperature drifts in the data that could not be corrected with the available data.

Similar readings were recorded for all thermowells at all velocities and Figures 4-9 show one-minute averages of data taken simultaneously from each thermowell, and each vertical scale is in units of microstrains (με), or 10^{-6} inches per inch. Several of the strain frequency plots include a 60-Hz component (or increasing multiples of 120Hz) that can be attributed to electrical noise and **should be ignored.** In each case, the helical thermowell is the top graph – please note the magnitude of the Y-scale is changing on each graph.

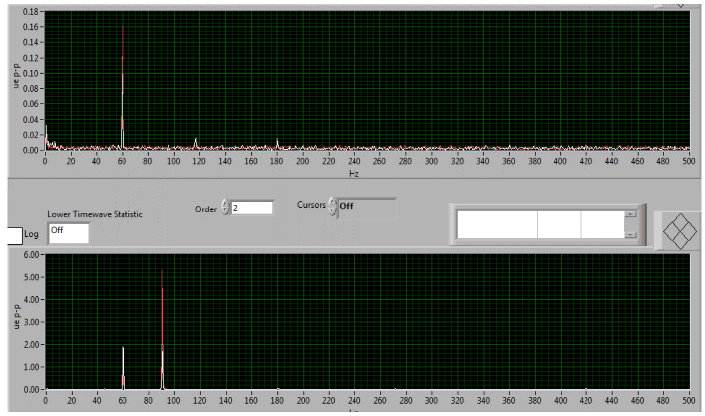


Figure 4. Frequency Responses of the Strain Gauges in the 12-inch Thermowells at 12.2 ft/s

In Figure 4, note that the peak strain amplitude is ~350 times larger for the ASME thermowell. The small peak at 117Hz for the helix is as expected due to the high turbulence created by the helical strake. The turbulence will create disturbance corresponding to a wide range of frequencies and so the thermowell would be expected to have slight increased strain above background noise at its natural frequency. The 60 Hz frequency component in both spectra is attributed to electrical noise (and also the peak at 180Hz and 300 & 420 & 540Hz in later graphs).

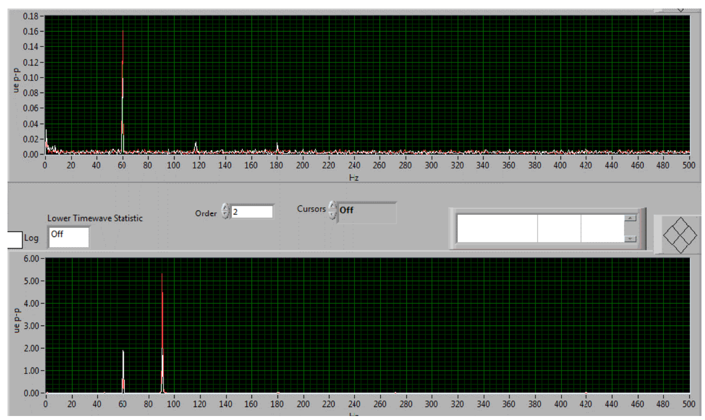


Figure 5. Frequency Responses of the Strain Gauges in the 12-inch Thermowells at 24 ft/s

As at the lower flow rate, Figure 5 clearly shows that the dominant frequencies of the cyclic strains are consistent with the frequencies of oscillation at the thermowell tips(as seen in the video files). The magnitude of strain in the helix thermowell is reduced by over 98%.

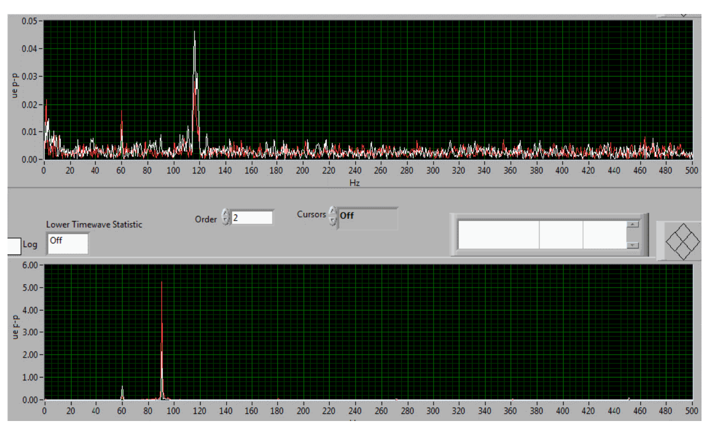


Figure 6. Frequency Responses of the Strain Gauges in the 12-inch Thermowells at 29.7 ft/s

Figure 6 shows, that even though the ASME thermowell is now outside of the lock-in zone, the magnitude of strain is in excess of 100 times greater than the helix thermowell.

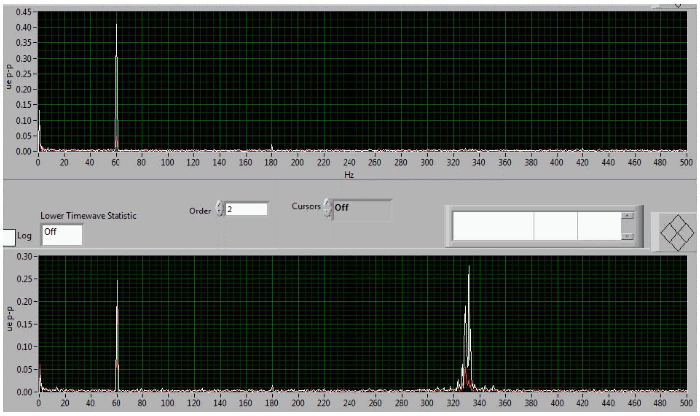


Figure 7. Frequency Responses of the Strain Gauges in the Six-inch Pipe at 46.5 ft/s

The ASME thermowell measured a cyclic strain at a frequency of ~329 Hz (this frequency matches the measured natural frequency of the thermowell and so is as expected). Figure 7 indicates the helical strake thermowell registered no significant strains at the expected frequency of 443 Hz (due to the geometry of the helical strake, the measured natural frequency of the helical thermowell is slightly higher than the ASME thermowell and so cyclic strains would be expected at this frequency if present) This elimination of strain above background noise is possibly because the low energy turbulence around the helical thermowell was not sufficient to deflect the shorter, stiffer thermowell (compared to the thermowell in the 12" line).

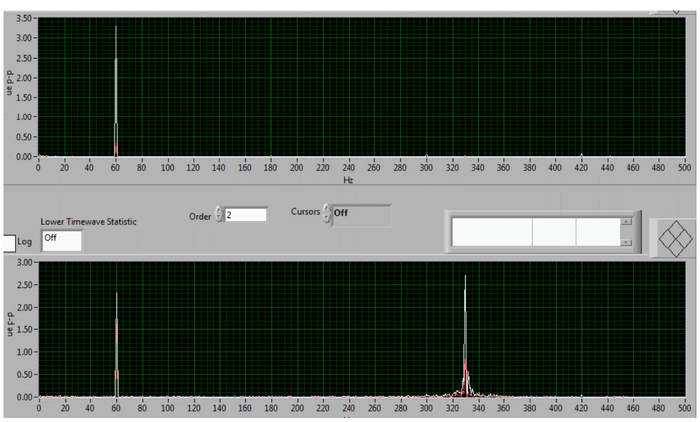


Figure 8. Frequency Responses of the Strain Gauges in the Six-inch Pipe at 93.4 ft/s

The primary frequency of the strains measured in the ASME straight thermowell were consistent with the vibration frequency of 329 Hz at the tip, whereas the helical strake thermowell registered no significant strains, confirmed in Figure 8.

As in the previous two figures, Figure 9 clearly shows the ASME thermowell has a clear cyclic strain at 329Hz with no significant strain in the helical thermowell.

The peak magnitude of the strains measured in the helical strake thermowell ranged from 0.02 με at 40% of flow capacity to 0.085 με at full flow (in the 12" line, no cyclic strain above background noise was measured in the 6"

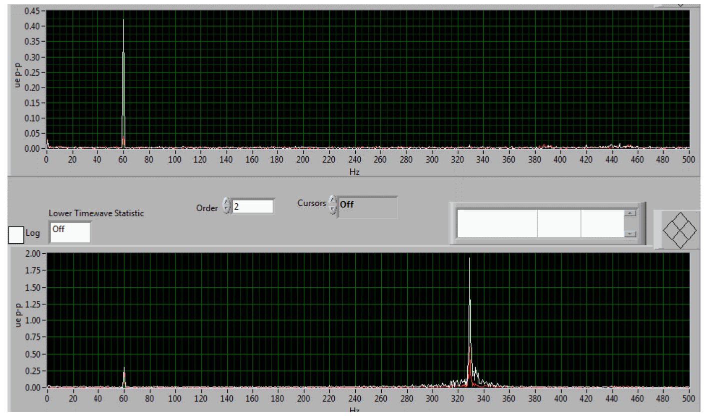


Figure 9. Frequency Responses of the Strain Gauges in the Six-inch Pipe at 108.1 ft/s

thermowells). By comparison, the measured strains in the ASME thermowell ranged from 5.2 με to 8.3 με over the same flows, a reduction in strain for the helical thermowell of 98.9% or more.

Video 5, although only captured non-technically, gives a very clear image of the indirect consequences of vortex shedding. Although we typically consider only the flange/shaft interface when designing sample probes and thermowells, this cyclic strain will pass into the connection point, nozzle or other associated structural element which can often be less ductile (for example Stainless Steel sample probe and carbon steel pipeline) and could potentially have significantly more catastrophic impact. Other than the direct safety issue with regards to failure, the potential damage to delicate instrumentation or physical impact to components, fittings and connections could cause reduced life or even leaks/failures to connected equipment.

Video 5 – Vibration for ASME thermowell – indirect impact (sound required)

Results – Accelerometer

A comprehensive review of the accelerometer data can be found in the testing report from the independent metering research facility (see link below). However, Figure 10 and 11 show the results of the testing at 24ft/s in the 12" line as an example. The graphs capture the vibration spectra averaged over a 6-minute period. Again, there are small peaks at 60 and 540Hz attributable to electronic noise. The helical thermowell registers acceleration at its natural frequency of ~0.35g compared to 6.3g for the ASME thermowell. Although this is a significant reduction (~94.5% reduced vibration), the more critical element is the lack of displacement (as seen on the videos and strain data) due to the thermowell never entering a resonant condition.

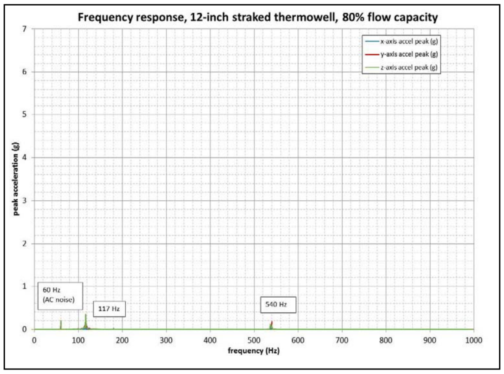


Figure 10 . Frequency Response of the Accelerometers in the tip of the 12" Helix Thermowell at 24ft/s

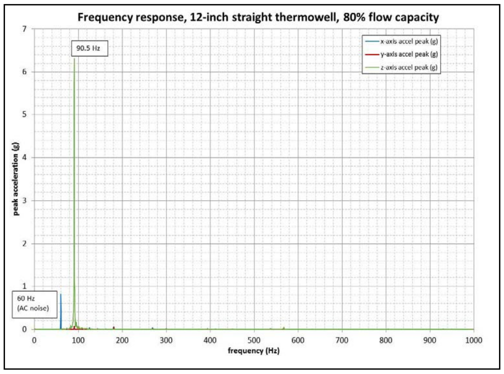


Figure 11. Frequency Response of the Accelerometers in the tip of the 12" ASME Thermowell at 24ft/s

Conclusion

The testing validated the ASME PTC 19.3 code in terms of calculating both the natural frequency and the wake frequency for a sample probe or thermowell. Although the natural frequencies of the 2 types of thermowell differed slightly (as expected due to helix geometry), across the full range of velocities tested there was clear vibration in both the in-line and transverse directions for a traditional ASME thermowell that were not present at any velocity for the helical thermowell.

Given the trends in the data from the 12-inch helical strake thermowell, the strain gauges in the 6-inch helical strake thermowell would have been expected to measure strains at a cyclic frequency around 440 Hz. However, no frequency content in the region around 440 Hz was measured (above the typical noise level of 0.01 με to 0.02 με across the spectrum). This is possibly due to turbulence created by the helix having insufficient energy to cause any deflection in the increased stiffness of the shorter thermowell (compared to the 12" line). This confirms that the helix is disrupting the vortices that would typically be shed and therefore, removing the cyclic strain on the thermowell/probe flange/shaft connection.

The strain due to the tip displacement was consistently 2 orders of magnitude greater for the ASME thermowell than in the helix thermowell (98% or greater reduction in strain). This crucial strain reduction proves that the dynamic wake frequency calculations according to ASME PTC 19.3 are now less relevant than the static bending and/or pressure/temperature calculations for a helical straked sample probe or thermowell. The static loads are now the driving design parameter when calculating the length, diameter and wall thickness allowable.

Although often ignored, the ASME thermowell continues to vibrate, albeit at a lesser magnitude due to the wake frequency not matching the natural frequency, even when outside of the lock-in zone.

An independent report focusing on the accelerometer data is available at http://orbitalgas.com/wp-content/uploads/2017/06/ OrbitalThermowellTestReport.pdf - please contact us at www.orbitalgas.com for more information.

* NOTE: the term ASME thermowell is in no way suggesting that this is ASME approved or recognized. It is simply a thermowell that has been fabricated according to the ASME PTC 19.3 standard

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