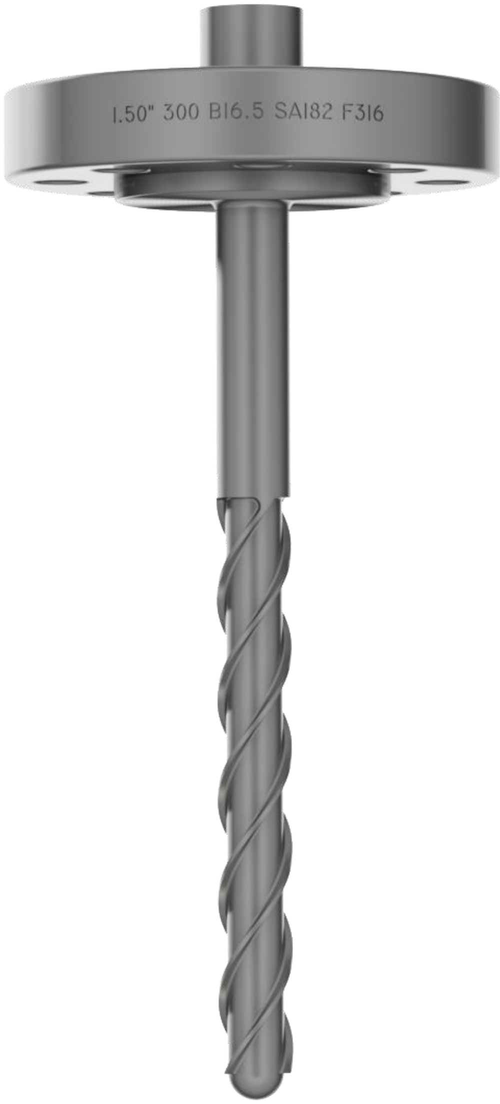
CFD Analysis of DHTW™ utilizing VE Technology®
A Helix Thermowell Design White Paper



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Introduction:

Thermowells are used to protect the instrumentation inside pipes or vessels and are commonly used in the petrochemical industry. The American Society of Mechanical Engineers (ASME) wrote a standard that establishes the practical design considerations for thermowell installations in power and process piping, known as ASME PTC 19.3 TW-2016. This standard helps manufacturers and users calculate the suitability of the thermowell in their given process conditions. This is done by subjecting the designed thermowell to multiple calculations. One of the calculations is to determine the frequency of the wake due to the vortex-induced vibrations (VIV) caused by the flow across the thermowell. The natural frequency of the thermowell is also calculated, and then, the two are compared. Thermowells must be designed to prevent the frequency caused by the VIV to approach their natural frequency, since this can cause catastrophic damage. Helical strakes have been added to cylindrical bodies in other industries to prevent the VIV and have been recently used on thermowells. This technology, as applied to thermowells, was patented by EnDet Ltd and currently licensed to Orbital Gas Limited with a sub license to Daily Thermetrics. For more information on the patents, please see www.orbitalgas.com/patents. This paper will discuss the effectiveness of the helical strakes on a thermowell by the utilization of Computational Fluid Dynamics (CFD) and a coupled CFD/FEA (Finite Element Analysis) software.

History:

ASME PTC 19.3 TW-2016 established the mechanical designs of the thermowells for the petrochemical industry. This code addresses the VIV phenomenon by calculating the frequency of the shedding of the vortices of the thermowell and comparing it to the resonant frequency of the thermowell. There are two separate forces on the thermowell caused by the shedding of the vortices. The first is an oscillating lift force which is transverse to the flow while the second is an oscillating drag force, in-line with the flow. The code uses a formula to determine the expected frequency of oscillations of both the drag and the lift force. In order to pass the code, these frequencies are compared with the calculated natural frequency. If the design does not pass these criteria, the thermowell dimensions must be changed in order to alter the resonant frequency of the thermowell or the velocity of the process must be lowered to change the frequency of the vortex shedding.

Historically, the thermowell designers could add velocity collars on the thermowell shaft to effectively adjust the fixed location (see Fig 3). This design works well if it is designed and implemented correctly, but, is generally labor-intensive to install and as of 2010, is not recommend by the ASME PTC 19.3 TW due to its significant failure rate. Another solution, commonly implemented, is to increase the diameter of the thermowell so that the strength is greater and the natural frequency is changed, but this causes a slower response time for the sensor inside the thermowell and can transfer the vibrational force to the nozzle. This solution can also be costly, especially when using exotic materials.

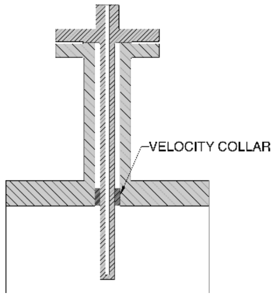


Figure 1 - Velocity Collar

Helical Strakes:

Helical strakes have been utlitized within other industries to solve the problem of VIV. The strakes disrupt the flow as it passes the solid body. This disruption causes flow irregularties and breaks up the vorticies. If designed correctly, the helical strakes prevent vortex shedding, and thus, eliminate the VIV.

The geometry of the strakes is important for the desired effect. Research, evaulation, and testing performed by EnDet Ltd. has concluded that the following geometry is in the ideal range (see Table 1), and will be used in this analysis (see Fig 2).

Typical Helical Dimensions	
Number of Strakes	3
Pitch	4x OD
Height	.12x OD
Width	.08x OD

Table 1 – Typical Helical Dimensions

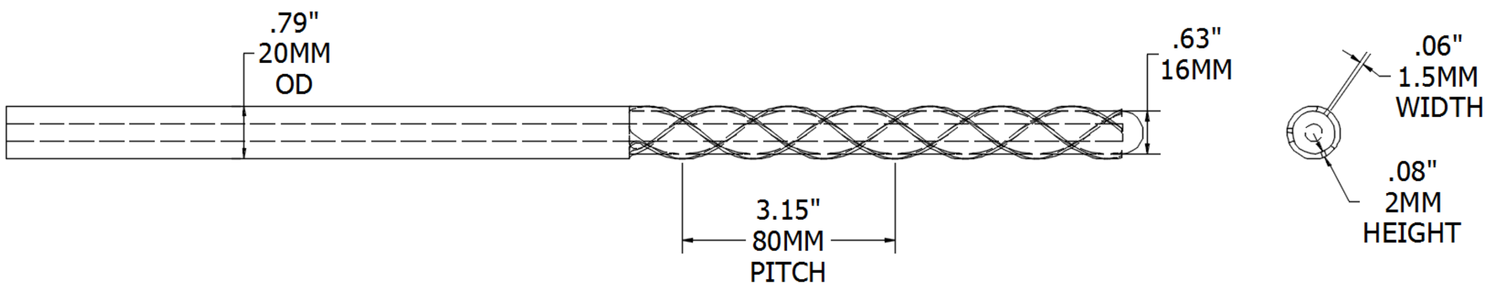


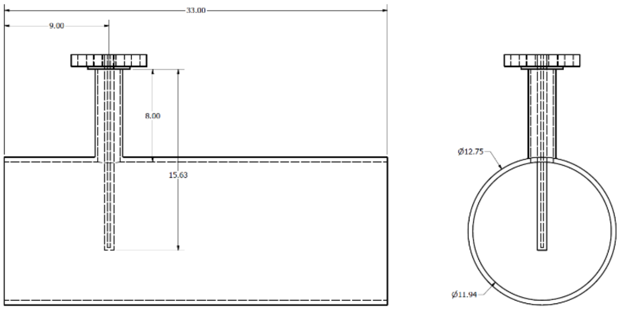
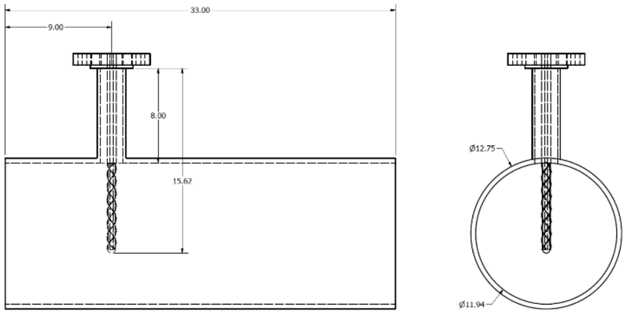
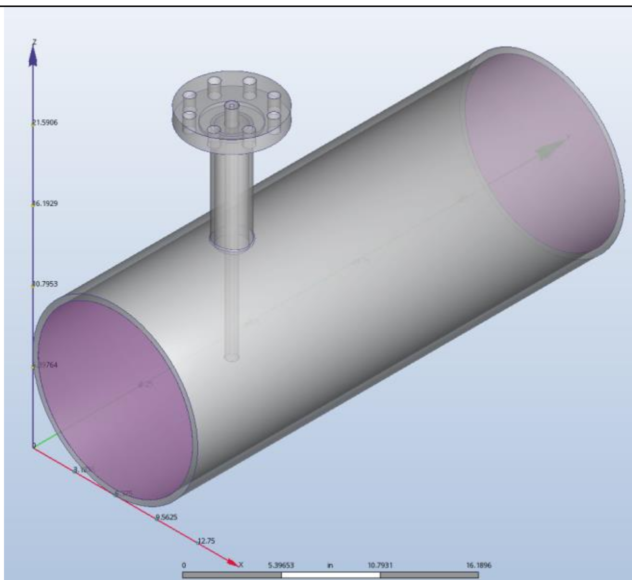
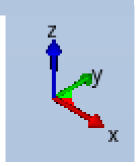
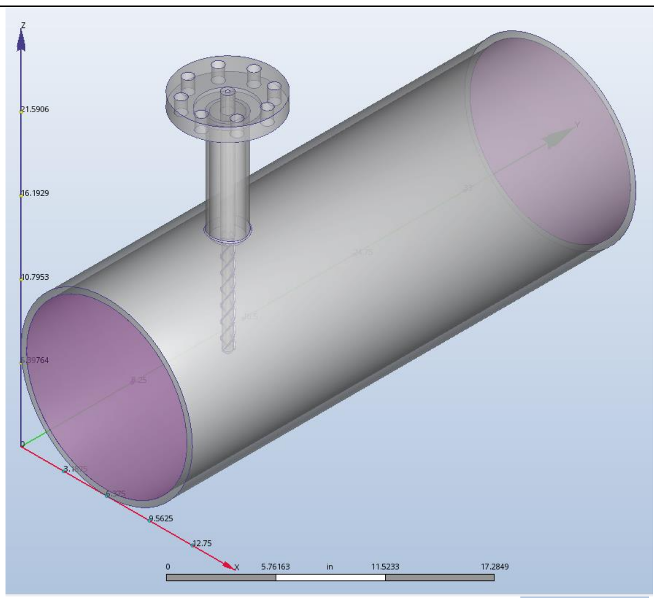
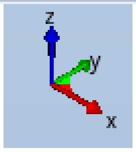
Figure 2 – Helical Dimensions Used in Analysis

Computational Fluid Dynamics (CFD) Analysis:

The effectiveness of helical strakes was tested using the CFD software. Both a standard cylindrical thermowell and a helix thermowell with helical strakes were modeled and compared. They were inserted perpendicular to a pipe to simulate the typical flow patterns of thermowells in the petrochemical industry. The purpose of the CFD simulation is to determine the quantitave and qualitative differences between the two model types. To ensure similarity between the models, all flow conditions and geometry shall be the same, except for the thermowell shank.

Model Geometry and Setup:

A cylindrical thermowell and a helical thermowell with the below dimensions were analyzed. Fig 3-4 show the dimensions of the section of pipe being modeled and how the thermowells are mounted. Fig 5-6 are 3D isometric views of the showing the simulation set up along with the cordinate system.

Cylindrical Thermowell	Helix Thermowell
Insertion Length = 15.625”	Insertion Length = 15.625”
Shielded Length = 8.00”	Shielded Length = 8.00”
 *Figure 3 – Clyindrical Thermowell 2D Dimensions*	 *Figure 4 – Helix Thermowell 2D Dimensions*
 *Figure 5 – Clyindrical Thermowell 3D View* 	 *Figure 6 – Helix Thermowell 3D View* 

Conditions:

The boundary flow conditions, shown in Table 2, were selected by analyzing the wake frequency from the ASME PTC 19.3 TW-2016 to ensure vortex-induced vibration.

Boundary Flow Conditions	
Fluid	Methane
Inlet Velocity	24 ft/s
Outlet	0 psi
Pressure	965 psi
Density	3.34 lbm/ft^3
Viscosity	0.01266 cP
Compressibility	.9

Table 2 – Boundary Flow Conditions

Solver Parameters:

Solver parameters, shown in Table 3, were selected based on the industry's best practices for vortex-induced vibrations and critical wake structures.

CFD Solver Parameters	
Turbulence Model	SST k-omega SAS
Flow	Turbulent Incompressible Flow
Advection Scheme	Modifed Petrov-Galekin
Solution Mode	Transient
Time Step	0.0001 seconds
Inner Iterations	3
Build	Autodesk CFD 2017.0.1
Solver	17.2.20170227

Table 3 – CFD Solver Parameters

Mesh Analysis:

The meshing for both of the simulations needed to be sufficiently dense to accurately model the flow around the cylinder and the critical wake structures. Turbulence model, SST k-omega SAS, allows for the use of wall layers, which were used to accurately depict the flow around the structures. The turbulence model also needed a high density of mesh elements to accurately detail the vortices. The wake zone was enhanced to capture the details of the vortices as they shed and traveled down the remainder of the pipe. Fifteen wall layers were selected to resolve the boundary layer and capture the initial shedding of the vortices off the thermowell. A wall layer provides smooth consistent meshing along a rigid body, which is critical to model the flow and wake accurately. Table 4 compiles the dimensions chosen for this simulation.

Meshing Dimensions for Both Models	
Wall Layers	15
Wall Layer Factor	.55
Wall Layer Gradation	1.45
Mesh Size over Wake Zone	10 elements / inch
Mesh Size Rest of Fluid	4 elements / inch
Total Amount of Elements in Cylindrical Model	8,935,812
Total Amount of Elements in Helical Model	8,246,859

Table 4 – Meshing Dimensions

Results:

Since the thermowells were modeled in three dimensions, cut planes were utilized to show how the flow interacts with the thermowell. These cut planes can be used with both models to show the qualitative difference in flow between of a straight cylindrical body to one with the addition of helical strakes.

Absolute Velocity shows the path and speed of the flow through the pipe around the thermowell (Fig 7-10). While the wake for each thermowell is similar in shape, the flow as it passes the thermowell is different. The cylindrical thermowell flow is uniform and has a large low velocity section behind the thermowell. The helix thermowell has alternating low and high velocity sections behind the thermowell.

Absolute Velocity (ft/s) – Side View

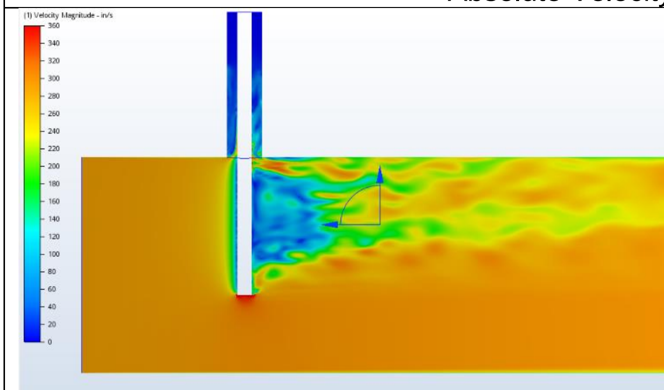


Figure 7 -
Absolute Velocity of Cylindrical Thermowell Side View

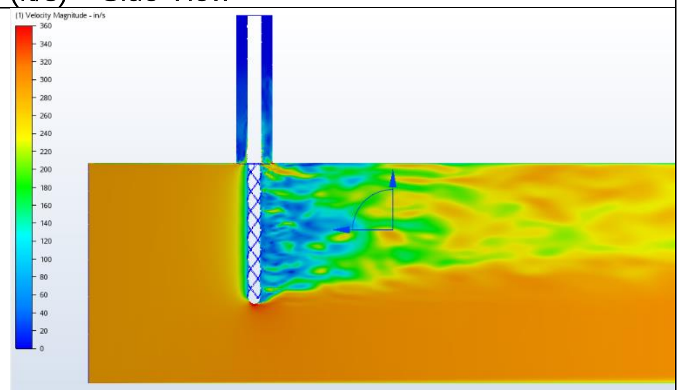


Figure 8 -
Absolute Velocity of Helix Thermowell Side View

Absolute Velocity (ft/s) – Top View

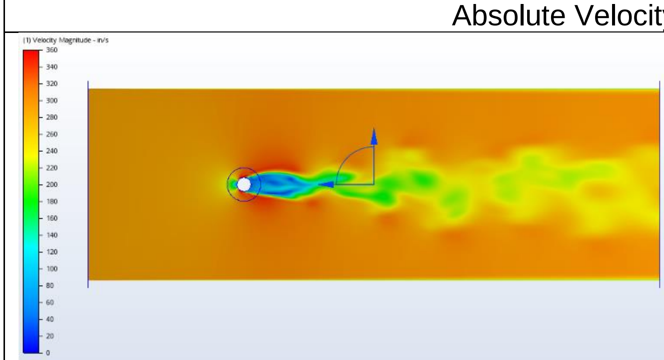


Figure 9 -
Absolute Velocity of Cylindrical Thermowell Top View

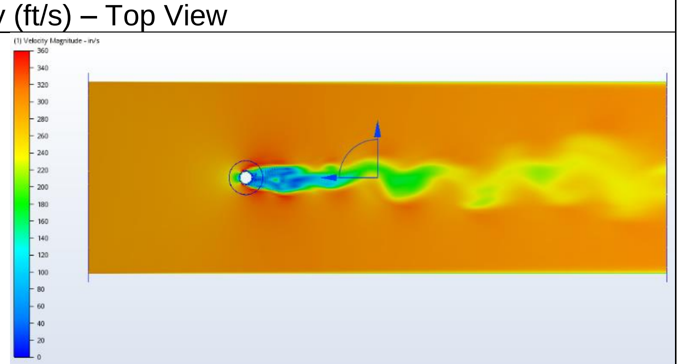


Figure 10 -
Absolute Velocity of Helix Thermowell Top View

Vorticity is a measure of the local spinning motion of a fluid flow. It is used to capture the magnitude of the vortices being created by the shedding. In the results below, the vorticity is expressed in terms of a direction that is perpendicular to the flow (Fig 11-14). This allows for a spectrum of colors to be applied, indicating which direction a particular vortex is spinning and its intensity. Red indicates that the flow is spinning clockwise while blue indicates that the flow is spinning counter-clockwise. The Z direction being referenced can be referred to in Fig 5-6. The still images below show that the cylindrical thermowell exhibits larger vortices, which extend to the length of the thermowell. The helix thermowell generates smaller vortices with one above the strake and one in the opposite direction below it.

Vorticity in Z Direction (1/s) – Side View

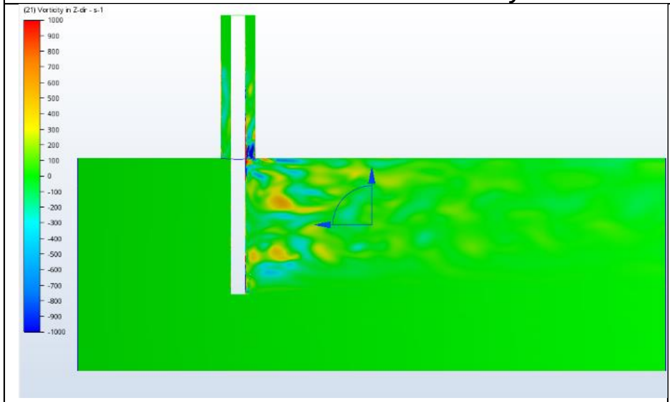


Figure 11 -
Vorticity in Z Direction of Cylindrical Thermowell Side View

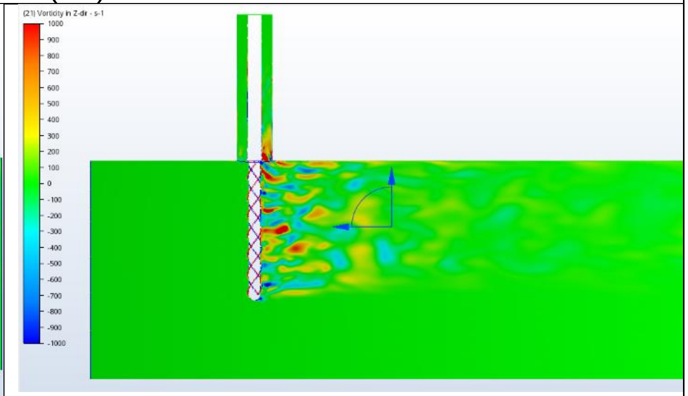


Figure 12 -
Vorticity in Z Direction of Helix Thermowell Side View

Vorticity in Z Direction (1/s) – Top View

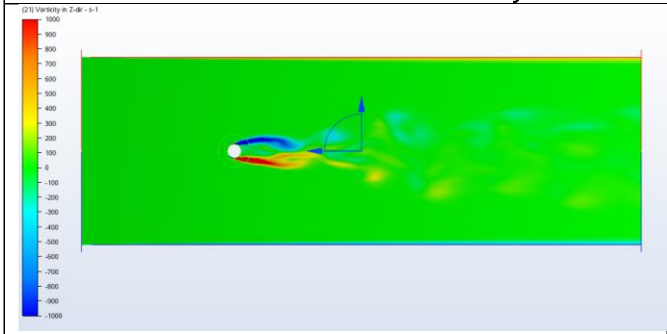


Figure 13 -
Vorticity in Z Direction of Cylindrical Thermowell Top View

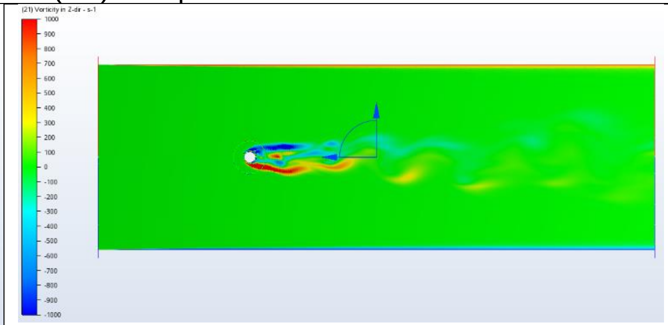


Figure 14 -
Vorticity in Z Direction of Helix Thermowell Top View

Turbulent Kinetic Energy (TKE) is the kinetic energy per mass of the turbulent eddies being produced in the flow. The higher the Turbulent Kinetic Energy, the more energy is taken from the flow and converted into turbulent eddies. The cylindrical thermowell produces large TKE and thus, more of the flow is converted into these eddies (Fig 15, 17). The helix thermowell has significantly lower TKE generation and thus, produces smaller local eddies (Fig 16, 18). The helix thermowell also has a smaller wake amplitude as compared to the cylindrical thermowell.

Turbulent Kinetic Energy -TKE (ft^2/s^2) – Side View

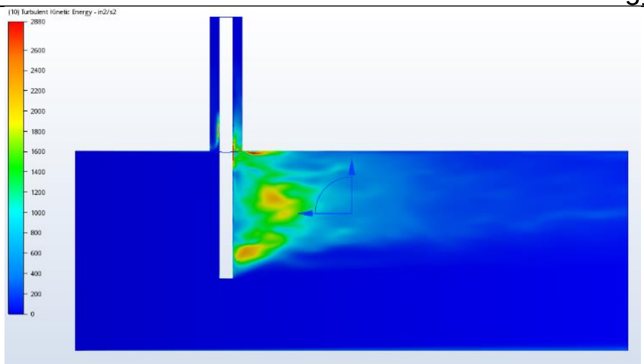


Figure 15 -
Turbulent Kinetic Energy of Cylindrical Thermowell
Side View

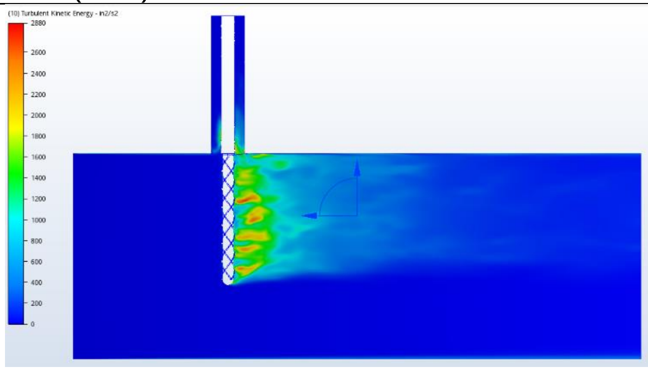


Figure 16 -
Turbulent Kinetic Energy of Helix Thermowel
Side View

Turbulent Kinetic Energy -TKE (ft^2/s^2) – Top View

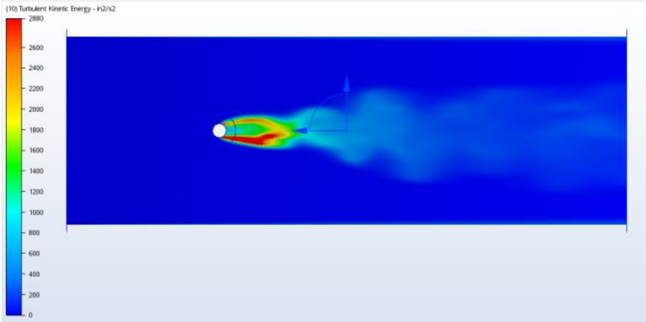


Figure 17 -
Turbulent Kinetic Energy of Cylindrical Thermowell
Top View

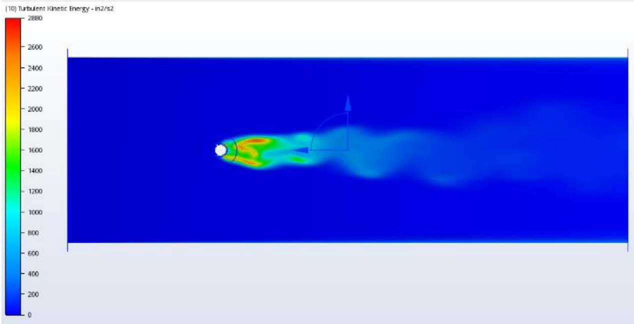


Figure 18 -
Turbulent Kinetic Energy of Helix Thermowell
Top View

CFD/FEA Analysis:

A coupled CFD and FEA (Finite Element Analysis) analysis was also performed to demonstrate the flow-induced vibration and the vortex induced vibration on both the cylindrical and helical thermowell. The coupled solver is 2-way and allows for a fluid structure interaction that can send data between the CFD and FEA solver during each transient iteration. Fig 19 shows the flow of the data between this type of solver. The results of this simulation were validated against a physical test performed at the well-respected testing laboratory in Texas using the same geometry and flow conditions as this simulation. Daily Thermetrics or Orbital Global Solutions can be contacted for a copy of the final test report.

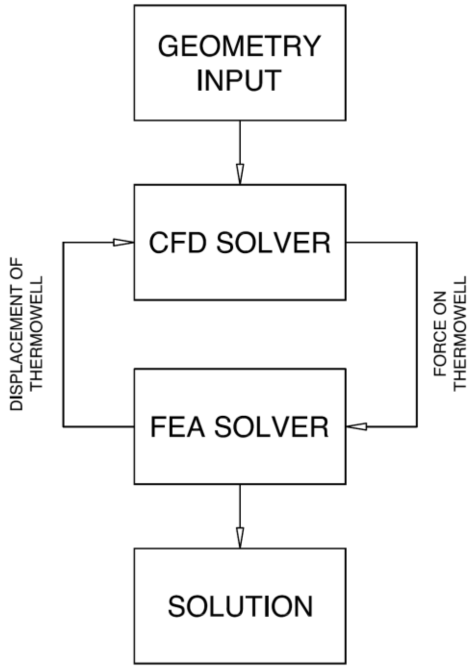


Figure 19 - Solver Flow Chart

Solver Parameters:

The solver parameters and boundary flow conditions were consistent with the values in Tables 2 and 3 except the flow was increased to 29.7 ft/s to match the physical test conditions. The solver was Ansys 18.1 utilizing the Fluent CFD solver and the transient Mechanical solver. The geometry was similar to Fig 3-6, but the length of the pipe was shortened to reduce mesh count since the coupled 2-way solver is more computationally intensive.

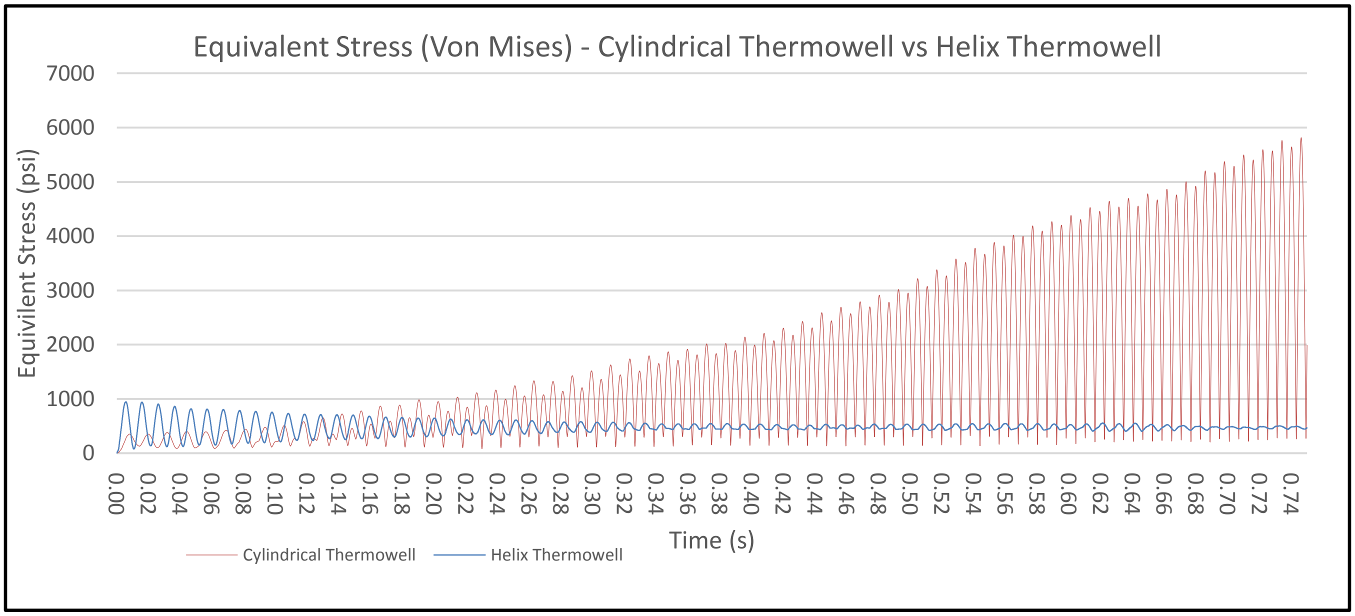
Mesh Analysis:

Dynamic Meshing was utilized to allow deflection of the thermowell and subsequent re-meshing of the fluid around the thermowell. This dynamic meshing was structured in a way to prevent creation or modifications of elements with a high aspect ratio that could reduce accuracy or cause a simulation failure. Wall layers, known as inflation layers in Ansys, were utilized to reduce the y+ on the thermowell boundary and to allow a consistent boundary layer around the thermowell. Due to the large Reynold's

Number of this simulation, Re ~ 800,000 for the cylindrical thermowell, a y+ ~ 1 was calculated to be ~ 5E-05 inch for the first inflation layer thickness. This was achievable on the cylindrical thermowell due to the relatively simple geometry, but a similar y+ was not obtainable on the complex helical strakes of the helix thermowell. A higher y+ was utilized for the helix thermowell in order for the simulation to run, but was meshed in such a way to incorporate inflation layers and a consistent boundary layer to maintain accuracy.

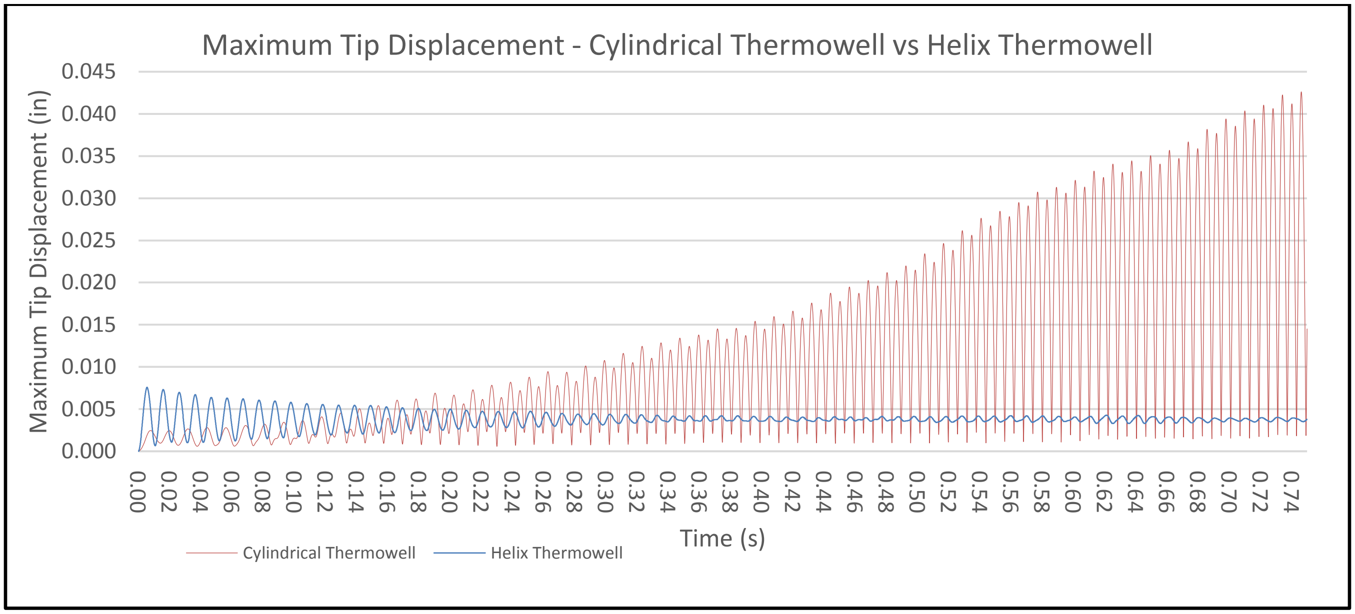
Results:

Mechanical results from the 2-way coupled analysis are computed and graphed below. Graph 1 shows the equivalent stress (Von Mises) on the thermowell due to the flow induced vibration. The results show an increasing amplitude on the cylindrical thermowells and a relatively stable and smaller amplitude on the helix thermowell. It is anticipated that the stress would continue to grow until it reaches a stabilized resonant vibration. This stabilization could take an extended length of time, which would be impractical and costly to model.



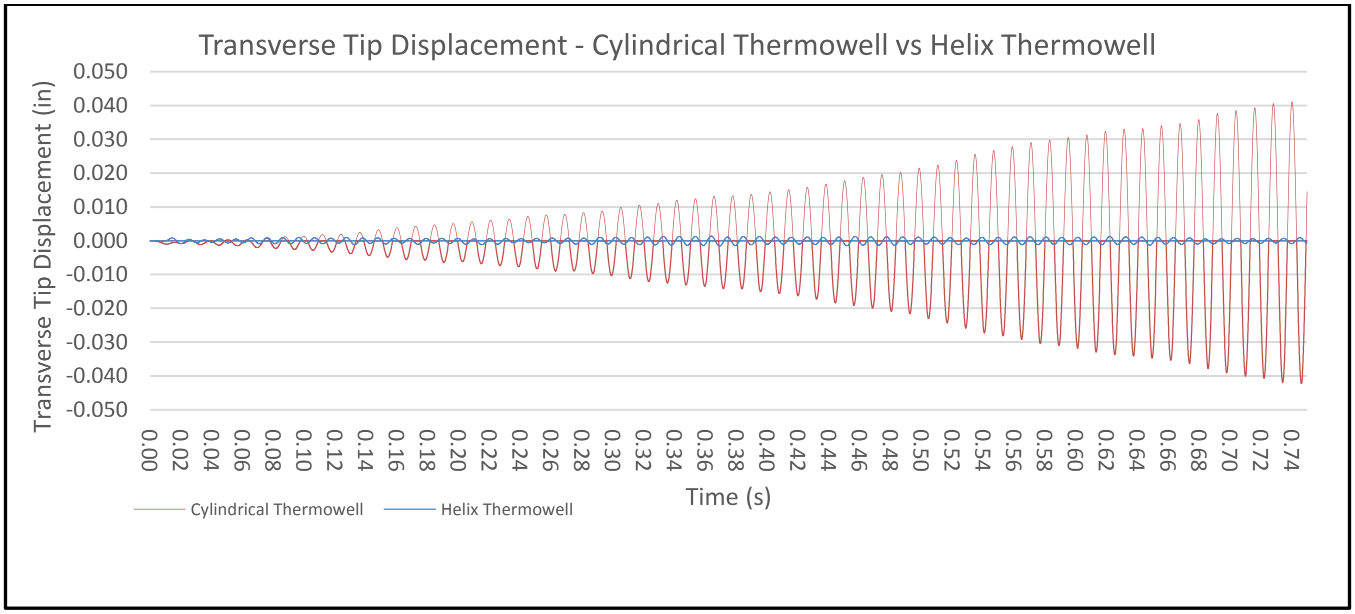
Graph 1 – Equivalent Stress (Von Mises) – Cylindrical Thermowell vs Helix Thermowell

Graph 2 shows the total maximum displacement of the tip of each thermowell. The displacement combines all directions of vibration and correlates with the equivalent stress in graph 1. Once again, each cycle the cylindrical thermowell increases in displacement as it approaches the stabilized resonant vibration. The helix thermowell has a larger displacement at the onset of the simulation largely due to the higher drag coefficient and because the simulation was initialized while the thermowells were static. This means that the simulation instantaneously would apply the full velocity to the fluid to the thermowell then calculate the displacement.



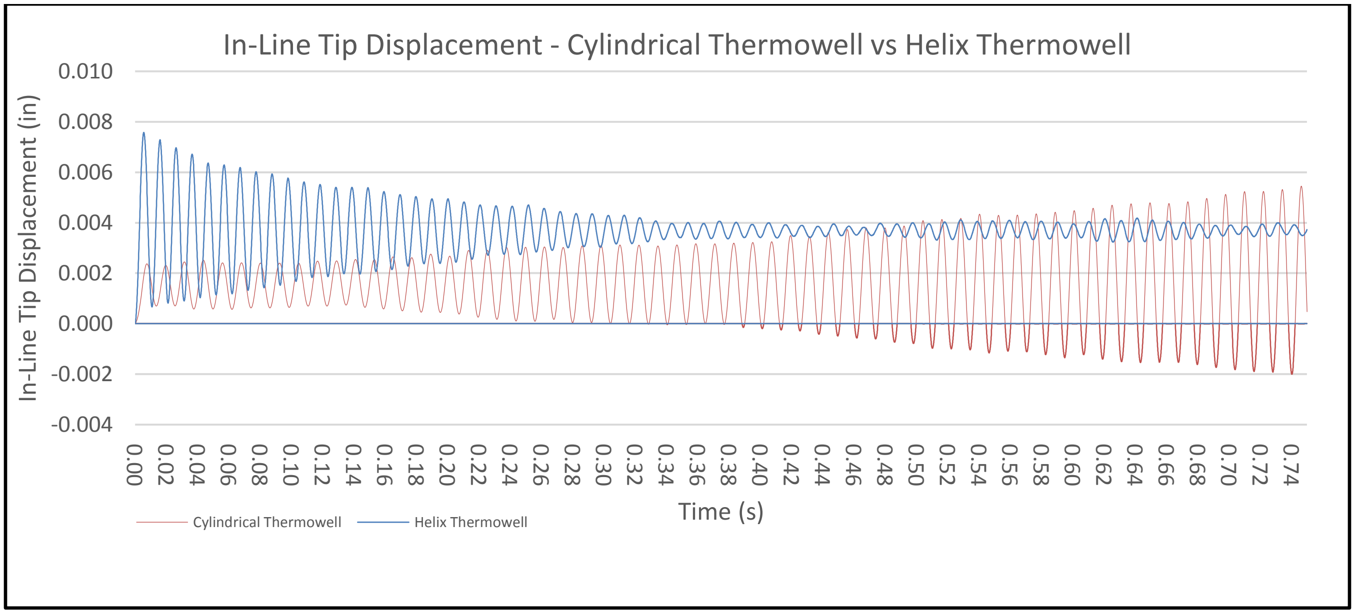
Graph 2 – Maximum Tip Displacement – Cylindrical Thermowell vs Helix Thermowell

Graph 3 shows the directional displacement in the transverse direction (perpendicular to the flow). This simulation and previous physical test at a testing laboratory were designed to resonate in the transverse direction as per ASME PTC calculations. This graph shows the cylindrical thermowell transverse vibration increasing over time, while the helix thermowell vibration is relatively small and steady. Physical testing showed a maximum displacement of 0.416 inches for the cylindrical thermowell and 0.0082 inches for the helix thermowell at these flow conditions. The maximum transverse tip displacement for the cylindrical thermowell was 0.0411 inches, but was still increasing. The maximum transverse tip displacement for the helix thermowell in this simulation was 0.00138 inches.



Graph 3 – Transverse Tip Displacement – Cylindrical Thermowell vs Helix Thermowell

Graph 4 shows the directional displacement in the in-line direction (parallel with the flow). As the simulation starts, the helical thermowell has more displacement due to a higher drag force than the cylindrical thermowell. As the simulation progresses, the helix thermowell reduces the in-line tip displacement and the cylindrical thermowell increases it. This vibration is considered stable and should not reach a highly magnified resonance. Physical testing showed a maximum in-line displacement of 0.0474 in for the cylindrical thermowell and 0.0088 in for the helix thermowell. This simulation reported a maximum in-line displacement of 0.00545 in for the cylindrical thermowell and 0.00758 in for the helix thermowell.



Graph 4 – In-Line Tip Displacement – Cylindrical Thermowell vs Helix Thermowell

Validation:

The 2-way coupled CFD/FEA simulation shows that the cylindrical thermowell has reached a resonant vibration and the displacement and stress is drastically increasing. The helix thermowell is stable and has minimal vibrations and stress, which is within the endurance limit of the stainless steel. These results are in agreement with test data retrieved from the testing laboratory, which shows amplified vibrations of the cylindrical thermowell and a stable helix thermowell. Both the simulation and the test validate the use of the ASME PTC code, which predicted that the wake frequency would cause an in-line resonant vibration of the ASME designed cylindrical thermowell.

Using ANSYS to determine the force and displacement on the thermowell, the average coefficient of drag, C_D, for the thermowells in this simulation was calculated to be:

Cylindrical Thermowell, C_D ~ .694
Helix Thermowell, C_D ~ 1.021

The cylindrical thermowell value is consistent for a cylindrical shape at a Re ~ 800,000, which is in the drag crisis zone. The helix thermowell drag coefficient is approximately 47% higher than that of the cylindrical thermowell, which is within the expected range. The current practice is to use more conservative drag coefficient values to determine static stress limits on the thermowells. Cd ~ 1.4 for standard ASME cylindrical thermowells and Cd ~ 2 for helix thermowells are appropriate for calculation purposes of Re > 1000.

Conclusion:

CFD simulation provided both qualitative and quantitative results, describing the differences between how a fluid flow interacts with a cylindrical thermowell versus a helical thermowell. The velocity and vorticity cut planes and charts show that the flow behaves differently when it reaches the different thermowells. The cylindrical model is uniform across the length of the body and thus, the flow reacts similarly. This produces big vortices that extend the length of the thermowell. The helix thermowell breaks up large vortices, as seen in the cylindrical thermowell, and produces smaller alternating vortices from the helical strakes. As the flow interacts with the strakes, it is directed to the top or the bottom. As shown in the velocity graph, this produces alternating high and low flow velocities in its wake. This also produces alternating smaller vortices, which generate much less Turbulent Kinetic Energy than the cylindrical thermowell. We believe that the vortices shed from the helical thermowell effectively negate each other. This is because each strake has a vortex shed above it and an opposite direction vortex below.

CFD analysis shows that the helical strakes are effective in producing smaller, dissimilar vortices shed from the thermowell. The cylindrical thermowell produces large vortices and a large area of Turbulent Kinetic Energy accounts for the vortex-induced vibration seen in actuality.

The 2-way coupled analysis including CFD and FEA was effective in validating the process against a known resonant vibration case. The software was able to model the flow driven vortex induced vibrations and calculate the stress and displacement on the thermowell. The data clearly shows that the helix thermowell is not subjected to the same resonant vibration as that the standard cylindrical thermowell.

We believe that the CFD and coupled CFD/FEA analysis, in conjunction with other physical testing, validates the use of helical strakes as an effective option to eliminate the VIV in thermowells.

Continued Research:

Although reasonable efforts were made to ensure an accurate simulation, the limitation of computational power dictated that the model size be reduced for a reasonable solve time. In this simulation, a powerful 8 core processor (25.6 GHz aggregate) was utilized, with the solve time being approximately 6-8 weeks total for both the CFD and CFD/FEA analysis. Increasing the mesh density of the fluid could show a more fully resolved wake. Additionally, using a higher computational solver, such as Large Eddy Simulation (LES) could show more details of the wake for analysis.

For the coupled analysis, it may be beneficial to increase the length of the section of the pipe in both directions to allow the fluid to become fully developed before it interacts with the thermowell and to examine the extent of the wake.

It could also be beneficial to examine the effectiveness of different helical strake dimensions and patterns as well as the differences between a straight cylindrical shank and the tapered or step-down shank. Possible benefits could include a wake that dissipates quicker or reduces manufacturing time.

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