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VortexWell

The Thermowell solution for when your design fails the ASME PTC 19.3 TW calculation

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Introduction:

Thermowell design is critical to the safe operation of today's many industrial applications. Failure of a relatively low cost Thermowell can have far reaching catastrophic consequences, and this can be highlighted in the 1995 failure at the Japanese Monju nuclear power plant.

Normally the Thermowell design and construction method is based around client instrument specifications and these in turn cross reference to industry standards such as API RP 551 and PIP PCCTE001, which in turn cross reference to ASME PTC 19.3 for design verification.

ASME PTC 19.3 was updated in 2010 to stand alone document ASME PTC 19.3 TW and now incorporates several references to research papers from Japan.

ASME PTC 19.3 TW The object of this Standard
Is to establish a mechanical Design standard for reliable service of tapered, straight, and stepped-shank thermowells in a broad range of applications. This includes an evaluation of the forces caused by external pressure, and the combination of static and dynamic forces resulting from fluid impingement.
(ASME PTC 19.3 TW)

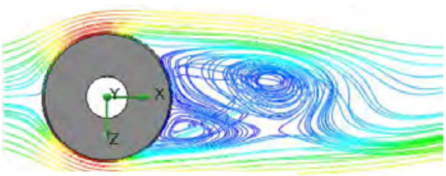
SPECIFICATION OF A THERMOWELL
Specification of a thermowell, including details of its intended installation and all intended operating conditions, is the responsibility of the designer of the system that incorporates the thermowell. The designer of that system is also responsible for ensuring the thermowell is compatible with the process fluid and with the design of the thermowell installation in the system. The supplier of the thermowell should state that calculations to demonstrate compatibility of the thermowell with those operating conditions specified by the designer are in conformance with this Standard (ASME PTC 19.3 TW)

Okazaki Manufacturing Company carries out calculations to ASME PTC 19.3 TW and also takes into account JSME standard JSME 012-1998: Guideline for Evaluation of Flow-Induced Vibration of a Cylindrical Structure in a Pipe.

Theory:

The forces potentially causing harmful oscillations on a thermowell stem when immersed in a flowing fluid are associated with a vortex street development in the wake of the thermowell.
This is also referred to as vortex induced vibration (VIV).
(Fig 1)

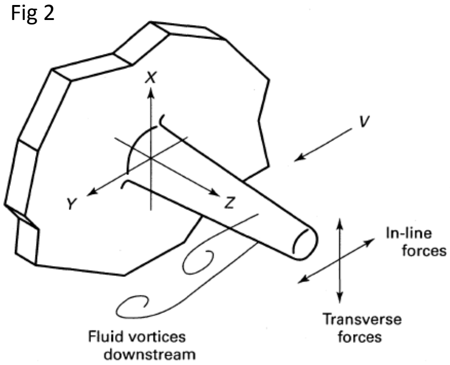
Fig 1



(T.Oakes , 8)

ASME PTC 19.3 TW now takes into account both the oscillating-lift force, transverse to the fluid flow at frequency fs and the Oscillating-drag force, in-line with the fluid flow at frequency 2fs
(Fig 2)

Fig 2



(ASME PTC 19.3 TW)

As the fluid velocity is increased, the rate of vortex shedding increases linearly while the magnitude of the forces increases with the square of the fluid velocity. The thermowell responds elastically according to the force distribution and its variation in time.

Should the vortex shedding rate coincide with the natural frequency of the thermowell, resonance occurs.

The fluid velocity at which this takes place is referred to as a velocity critical. There are a minimum of two critical velocities for each natural frequency of the thermowell

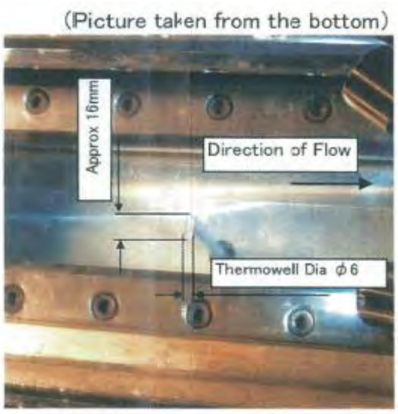
Since the in-line force fluctuates at twice the frequency of the lift excitation, the corresponding velocity critical is approximately one-half that required for lift resonance.

For any given fluid velocity, both forces are acting on the thermowell with the result that the tip of the thermowell sweeps out an orbital (Lissajou figure) that changes shape as the fluid velocity is increased. (ASME PTC 19.3 TW)

Thermowell design and validation should now take into account both these forces.

This movement can been seen in Okazaki video file on request and also partially on still photograph (Fig 3) shown in our test report AD-5274

Fig 3



Calculations:

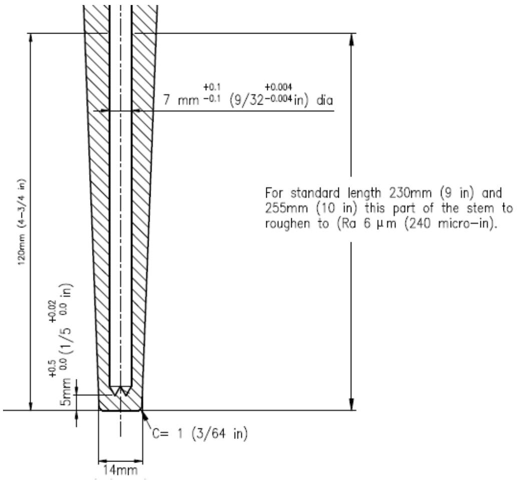
ASME PTC 19.3 TW shows clear definition of when and how calculations should be carried out and the reader is referred to this document for a fuller understanding.

When a calculation is required

At very low fluid velocities, the risk of thermowell failure is greatly reduced. The calculations of natural frequency and corresponding-frequency ,steady-state stress and oscillating stress do not need to be performed provided the following criteria are met:

(a) The process fluid has a maximum velocity less than 0.64 m/s (2.1 ft/sec).

Fig 4



(Shell S38.113)

(b) The thermowell dimensions satisfy the limits
(1) A 2 d > 9.55 mm (0.376 in.)
(2) L < 0.61 m (24 in.)
(3) A > B > 12.7 mm (0.5 in.)

(c) The thermowell material satisfies S > 69 MPa (10 ksi) and Sf > 21 MPa (3 ksi).

(d) The thermowell material is not subject to stress corrosion or embrittlement.

The calculation of the external pressure rating shall still be performed.

Concern for Shell Design Thermowells
This Standard applies to thermowells with an as-new surface finish of 0.81 µm (32 µin.) Ra or better. Stress limits given in subsection 6-12 are not valid for thermowells manufactured with rougher surfaces. (ASME PTC 19.3 TW)

Shell Drawings S38.113 and S38.114 shows for the last 120mm the surface is roughened to 6 Ra (Fig 4) so these designs are outside scope of the standard

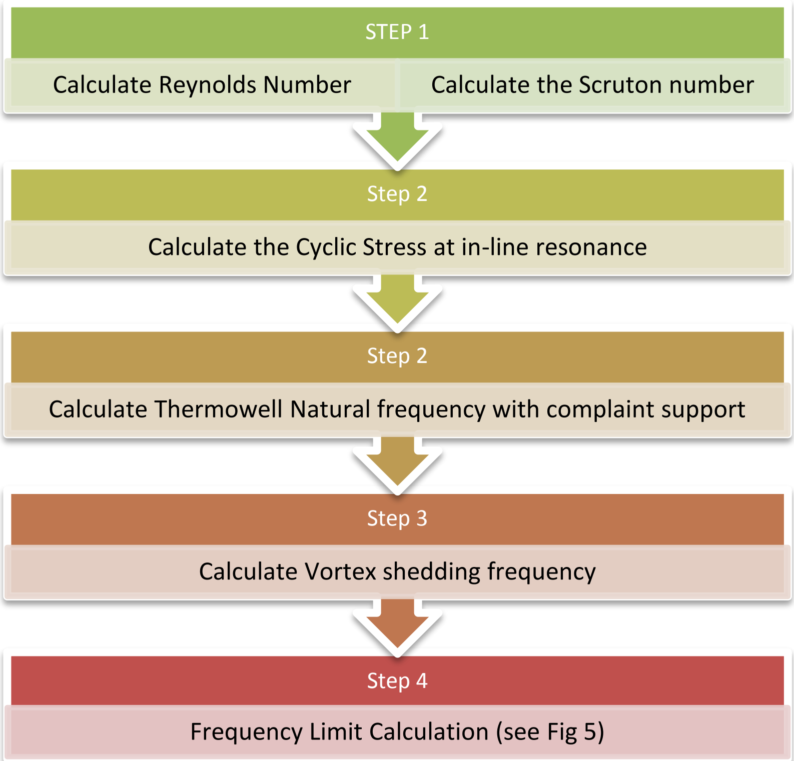
What is a Calculated?

Much attention has been focused on the frequency limit of the thermowell and how the natural frequency and wake frequency ratios compare and effect on the safe operation of the thermowell but in fact there are 4 criteria that the thermowell design must meet against the applicable process conditions.

- Frequency Limit
- Dynamic Stress Limit
- Static Stress Limit
- Hydrostatic Pressure Limit

Frequency Limit Calculation

ASME PTC 19.3 TW now provides calculations and acceptance criteria based on the given process conditions and thermowell design. The reader is again referred to this standard for a full explanation and we will summarise for an overview understanding.



If $N_{SC} > 2.5$ and $Re < 10^5$, in-line resonance is supressed, and the installed natural frequency of the thermowell shall satisfy

$$f_s < 0.8 f_n^c$$

If the thermowell fails the cyclic stress condition for operation at the in-line resonance condition, the installed natural frequency,

$$f_s < 0.4 f_n^c$$

In cases where the thermowell passes the cyclic stress condition for operation at the in-line resonance condition, care shall still be taken that in steady state the flow condition will not coincide with the thermowell resonance. The steady-state fluid velocity should meet one of the following conditions.

$$f_s(\text{steady state}) < 0.4 f_n^c$$

$$0.6 f_n^c < f_s(\text{steady state}) < 0.8 f_n^c$$

Fig 5

Dynamic Stress

Calculation carried out in line with ASME PTC 19.3 TW

Static Stress limit

Calculation carried out in line with ASME PTC 19.3 TW

Hydrostatic Pressure Stress and Limit

Calculation carried out in line with ASME PTC 19.3 TW
For flanged thermowells note is taken to check thermowell flange rating against instrument data sheet due to thermowell material pressure ratings verses process pipe material pressure rating,

316 & 316L have a lower pressure rating compared to Carbon Steel

	Nozzel ID			
Nominal Pipe Size	40	80	160	XX Strong
1 1/2"	40.9	38.1	34.0	27.9
2"	52.5	49.3	42.9	38.2

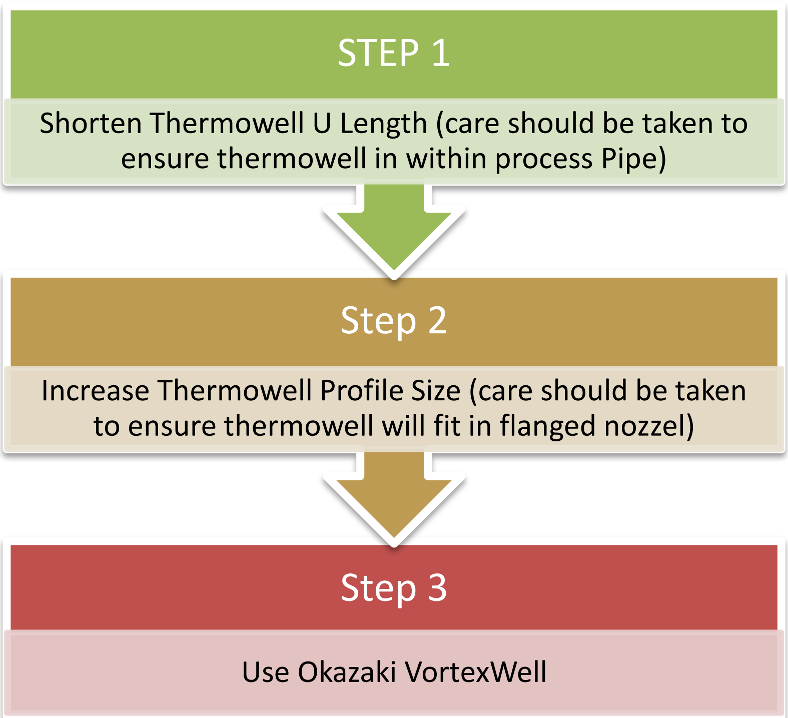
	Maximum Well OD			
Nominal Pipe Size	40	80	160	XX Strong
1 1/2"	33	30	26	20
2"	45	41	35	30

What happens when the thermowell fails the calculation?

ASME PTC 19.3 TW only defines the test criteria and offers no solution when the thermowell design fails the series of equations based on the operating conditions.

Okazaki has formulated a procedure drawing on over 50 years of engineering and manufacturing experience, this combined with a detailed understanding of client and international engineering standards and best practises give us a unique series of solutions to ensure correct thermowell design.

By following these detailed simple steps a solution can be found in a quickly and cost effective manner.



By decreasing the thermowell length this increases the natural frequency but with a flanged thermowell there is the increased length of the process connection and associated stub connection length. The thermowell tip must be suitably positioned within the process pipe to ensure the sensor is also positioned in the correct position. There is much debate from engineer to engineer on the correct length into the process pipe and some guidance can be taken from API RP 551 which states the following.

"A thermowell installed perpendicular or at 45-degree angle to the pipe wall should have a minimum immersion length of 2 inches and a maximum distance of 5 inches from the wall of the pipe."

Okazaki Manufacturing VortexWell (Fig 7)

Fig 7

After the failure of a thermowell which had passed a calculation based on ASME PTC 19.3 1974 at the Japanese Monju nuclear power plant in 1995. Okazaki being one of Japan's largest manufacturers of temperature assemblies started its own research into how thermowell designs could be improved.

With the publication of JSME 012-1998 and based on our own in house preliminary research we decided to look to industry for an alternative way to suppress the wake frequency, this would if successful remove the problem of and offer a real alternative solution.

JSME 012-1998 shows the best methods to decrease the vibration caused by a Karman Vortex Street is as we discussed earlier to make the thermowell shorter or larger in diameter. When this is not possible then countermeasures to avoid the occurrence of the Karman Vortex Street should be used. There are several method mentioned (Fig 8) but after our initial R & D the Helical strake design was our choice due to the suitability on the Thermowell stem.

The use of Helical Strakes is referenced in many documents and patents.

Scruton, C., Walshe, D.E.: US3076533 (1963).

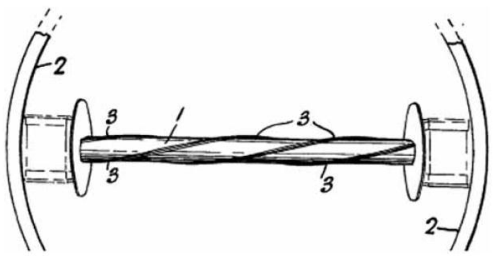


Fig 8

Helical strakes invented by Scruton and Walshe 2-Wind tunnel body, 3-helical strakes (equi-angularly spaced and wounded on The cylindrical body).(Fig 8)

BS 4076 which recommend their use of Helical strakes for prevention of "Von Karman vortex shedding.

R D Blevins Flow-Induced Vibration. Van Nostrand Reinhold Company, New York, 1990. (Fig 8)

Okazaki Manufacturing Research

Once the technical research was carried out and the Helical Strake pitch, quantity and thickness was decide.

Tests carried out at Tamagawa University showed in a direct comparison between a standard thermowell profile and that fitted with Helical Strake profile then the latter showed no adverse effects from the various flow rates subjected on the test samples.

At the higher flow rate the standard thermowell showed the signed of vibration and failed due to metal fatigue.

In 2008 Okazaki UK commissioned a detailed CFD analysis of both a standard thermowell and the now branded VortexWell profile. (Fig 10 shows comparison plots)

This report showed three clear findings firstly the short comings with the at time ASME PTC 19.3 1974 code and that our research information and Japan university test were correct.

The following was shown within the report

“It was found that the thermowell with helical strakes demonstrated no regular vortex shedding. While the flow behaviour varied significantly along the length of the thermowell it was observed that little or no time dependent changes occurred and the results were considered dynamically stable in all cuts along the length The plots showing flow streamlines provided an excellent visualisation of the influence of the helical strakes. It’s suggested that the strakes sufficiently disturb the flow in the wake region such that no regular vortexes can form. The strakes also encouraged cross plane flow behaviour (along the thermowell length) to an extent that was not observed with the standard thermowell. It’s thought that this process also helps to interfere with vortex formation.”

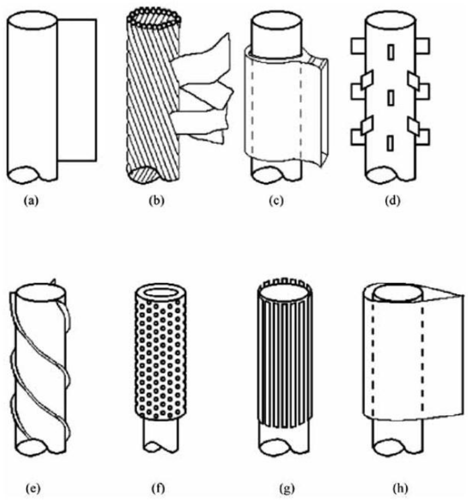


Fig 9

In December 2012 Evaluation International published its report E 1937 X 12 were a comparison trial had been carried out by TUV SUD NEL at their East Kilbride facility.

The conclusions from this report

“A comparison of dynamic performance and mechanical stresses indicates that the VortexWell has significantly outperformed the standard thermowell in this project”

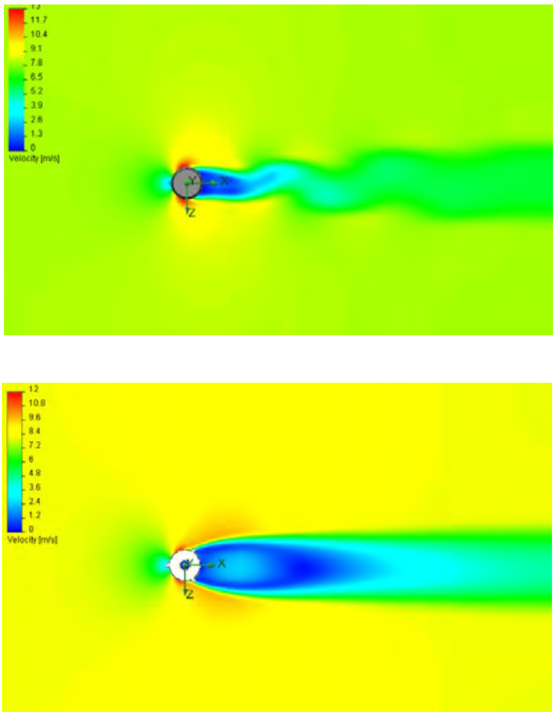


Fig 10

Conclusion

As end users, manufacturers and design engineers carry out thermowell calculation to ASME PTC 19.3 TW more and now with the inclusion of this requirement in the new version of ASME B31.1 due to be published in 2014 the amount of thermowell calculation failures increases. It has been reported

“By way of example, 2,571 thermowell calculations based on real data of thermowell calculations carried out in the past were evaluated. The comparison of the results shows that the probability of a thermowell calculation not passing the test with respect to the dynamic consideration in the examples under investigation increases by 27,9 %.”

The VortexWell designed and manufactured by Okazaki Manufacturing Company offers a credible solution to overcome increasing failures.