Technical Description

TD/TP–002 Issue 1

Wake Frequency Calculations – Solid Drilled Thermowells

What is a thermowell?

A thermowell is a pressure-tight receptacle that protrudes into a pressure vessel.

What are the engineering concerns?

At first sight, the major engineering concern is that the connection to the outside of the vessel should retain the forces exerted by the pressure inside. Whilst this is true, it is far from the whole story. In pipelines, the thermowell extends into a flowing fluid which exerts its own forces upon the stem[1]. Static forces are exerted by the mass of the fluid impacting on the stem. However, in high flow rates at high Reynolds numbers, the stem sheds vortices. Known as 'Von Karmen vortices', they present a danger when their frequency of shedding approaches the harmonic frequency of the stem.

An American Standard Performance Test Criteria (PTC) exists that describes the accepted method of calculating the harmonic frequency of the thermowell stem. ASME PTC 19.3 1974 (reaffirmed 1998) references work carried out by Murdock[2], which is now the accepted standard for harmonic frequency analysis of thermowells. Given the calculated harmonic frequency of the stem, the standard provides a method of calculating the induced frequency from the vortices. The standard then requires a safety margin to be applied such that the induced frequency is no more than 80% of the thermowell harmonic frequency.

A great deal of discussion has taken place as to whether Murdock's formulae are an over simplification of the problem of wake frequency analysis. However, the standards have yet to adopt an improved method. It is therefore reasonable, but not required, to consider increasing the margin of safety. Many plant engineers now consider a margin of 25% or 30% to be more acceptable than the 20% given by the standard. However, much of this is based upon natural engineering caution with little objective data being available.

Whilst it is without doubt that harmonic frequency failure exists and that thermowell failure for any reason is potentially disastrous, the only internationally recognized tool that the instrumentation engineer can turn to is ASME PTC 19.3. Where the fluid flow rate is high (typically in gas flows) and the damping effect of the fluid is low, it is advisable to run a calculation. The question then is what margin of safety to apply. The standard demands 20% which, for most environments, should be satisfactory. Where the consequences of a failure present a significant threat to the plant or to life, a larger margin may be advisable.

If a particular thermowell fails to meet the acceptance criteria laid out, there are a number of possible solutions:

Change the geometry of the thermowell.	This also changes the resonant frequency, so a shorter or thicker thermowell may well pass the criteria.
Ensure that the temperature element is positioned correctly within the pipe.	Many plant engineers believe that, to operate effectively, a temperature element must be centred in the pipe. In practise, so long as the measuring element is within the middle third of the pipe, there is no reason to expect any detrimental effect on the measurement accuracy.
Fit a velocity collar (flanged thermowells only).	This device forms a tight fit within the standoff and effectively shortens the unsupported length of the stem. Velocity collars can be expensive to produce and should be considered only after the other alternatives have been discarded.

1. The classic solid drilled thermowell is made from bar stock and drilled from one end only. The connection into the plant can either be by welding, screwed connection or flange. The stem of a thermowell is that part which extends into the vessel.

2. J.W.Murdock, Power Test Code Thermometer Wells, journal of Engineering for Power, vol. 81, 1959.

Calculation of thermowell stresses and verification of design suitability

Reputable suppliers of solid drilled thermowells for the most demanding of process applications are only too happy to provide an individual calculation of the stresses induced upon and the relative strength of their thermowells. As previously described, the reference work for these calculations are ASME PTC 19.3 and the work of Murdock. The stresses induced by static forces (pressure and bending stress) and the ratio of the resonant frequency to the induced frequency under operating conditions are all results of the calculations.

ABB are capable of producing calculations based on Murdock's work to verify the integrity of any thermowell solution proposed for any application. The inputs and outputs from the calculation are:

S Allowable stress of the material at the temperature of use (psi)

E Modulus of elasticity at the temperature of use (psi)

γ Specific weight (lb/in^3)

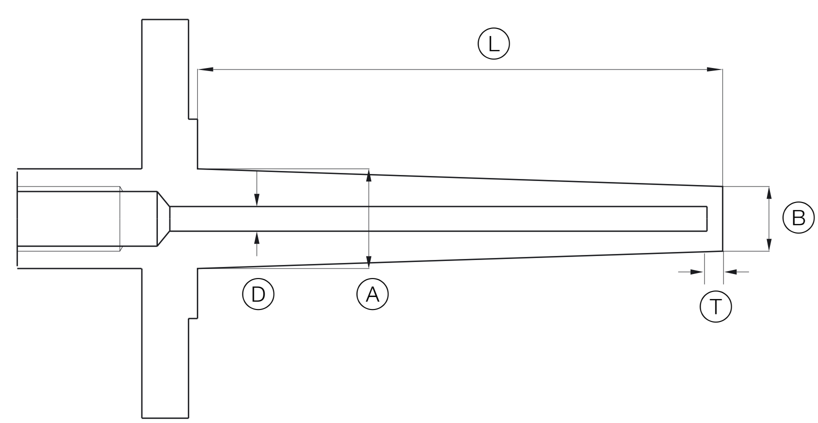
Information required for the fluid

Operating temperature (ºC)

Operating pressure (bar)

Specific volume (m^3/kg)

Velocity (m/s)



(A) The outside diameter at the support point (mm)

(B) The outside diameter at the tip (mm)

(D) The inside diameter of the bore (mm)

(T) The thickness at the tip (mm)

(L) The length from the support to the tip (mm)

Thermowell Dimensions

Given all of this data, the calculation returns additional data in the form shown on page 5. The data of particular interest from this list are:

- the frequency ratio – must be 0.8 or lower
- the maximum allowable pressure – must be greater than the operating pressure
- the calculated limit of length – must be greater than or equal to the unsupported length of the stem.

Other factors are quoted such as the constants KF, K1 through to K3. These factors are used by the calculation to determine the relevant points above. Also included in the calculation report are the data supplied for the calculation; this allows for a check to be made that these data are in fact correct. It is normal practice that, where these calculations are requested, they are retained by the supplier for reference as well as being supplied to the customer.

Calculation Data

Thermowell Calculation Program version 00-03-31

ASME Performance Test Codes Supplement on Instruments and Apparatus / Part 3: Temperature Measurement

ASME PTC 19.3 – 1986
ANSI PTC 19.3 – 1986

Constants KF, K1, K2, K3 calculated according to:

J.W.Murdock, 'Power Test Code Thermometer Wells' – Journal of Engineering for Power, Vol. 81, 1959
(ASME PTC 19.3 – 1986, Chapter 1, Reference [2])

Thermowell dimensions:

Diameter at support point A	20.638 mm	0.813 in.
Diameter at tip B	15.875 mm	0.625 in.
Diameter of bore D	6.655 mm	0.262 in.
Thickness of tip T	4.763 mm	0.188 in.
Length from support to tip L	63.500 mm	2.500 in.

Thermowell material data:

Temperature	426.670 °C	800.006 °F
Allowable stress value S	89.632 N/mm^2	13000.000 psi
Modulus of elasticity E	166164 N/mm^2	24100000 psi
Specific weight	8.027 kg/dm^3	0.290 lb/in^3

Fluid data:

Temperature	426.670 °C	800.006 °F
Pressure P0	300.000 bar	4351.130 psig
Specific volume	0.004 m^3/kg	0.064 ft^3/lb
Velocity V	50.000 m/s	164.042 ft/s

Calculation constants:

Constant KF	2.068992
Constant K1	0.412130
Constant K2	37.460594
Constant K3	0.116050

Vibration analysis:

Natural frequency Fn	3017.818 Hz
Wake frequency Fw	692.913 Hz
Frequency ratio R	0.229607
Magnification factor FM	0.055654

Maximum pressure / maximum length:

Max. allowable pressure	369.400 bar	5357.695 psig
Calculated limit of length	159.736 mm	6.289 in.

Result: Thermowell meets all requirements

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