# TECHNICAL INSIGHTS

# THERMOWELL GUIDE

## BASICS OF SELECTION AND DESIGN

***The thermowell is an essential device in industrial applications, designed to protect temperature measuring instruments from the harmful effects of high pressure, corrosive media, or dense and/or fast-moving fluids. Used in critical environments such as power plants, refineries, chemical industries, the oil and gas sector, and sewage treatment plants, thermowells are crucial for monitoring extreme temperatures of air, gases, or liquids. Choosing the appropriate thermowell may seem like an easy task, but there are several lurking difficulties, and a mistake can lead to significant consequences. This guide therefore aims to provide the basic knowledge for an informed choice.***

# INTRODUCTION

When planning a temperature measurement application, a lot of importance is given to the choice of sensor, however, less attention is often paid to the mechanical components of the sensor assembly, particularly the thermowell.

Although the thermowell may appear to be the simplest and least critical component, it is actually crucial because it directly and significantly influences sensor lifetime and measurement accuracy and protects the closed process by ensuring plant and personnel safety.

Knowing the process conditions affecting thermowell performance, basic design and installation criteria is essential to selecting the best thermowell for a given application as well as performing the relevant calculations can make the difference between reliable temperature measurements and unreliable, unsafe and expensive measurements.

Temperature measurement is often an invasive procedure, as a sensor protected by a thermowell is inserted into a pipe, tube, or process vessel.

While the sensor is measuring temperature, the thermowell absorbs the stresses of the process, allowing the sensor to function properly. A correctly designed thermowell must be able to withstand all process conditions with minimal impact on the responsiveness and accuracy of the temperature measurement.

Designing a thermowell for optimum performance therefore starts with defining all the conditions that can cause it to degrade, damage or fail. Next, it is necessary to determine what characteristics are required for the thermowell to withstand the worst application conditions.

Once the application conditions have been defined, the next step is to outline the basic design: although the design of the thermowell can take many variations, the fundamental criteria are the definition of materials, shape, size and type of process connection.

# THE PROBLEM OF VORTICES

In most cases, thermowell failures are not primarily due to the effects of pressure or temperature on them; the calculations necessary to ensure adequate strength under specific conditions are well known, allowing for the correct selection of wall thickness and the length of the thermowell.

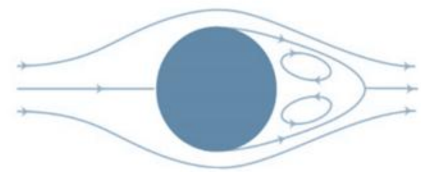
Less well known and more dangerous are the effects of vibrations on thermowell. When an object is immersed in a moving fluid, the flow can generate hydrostatic and aerodynamic forces around the object. Under certain conditions, the fluid flowing around the thermowell creates a vortex trail known as Kármán vortices.

These vortices rotate in opposite directions and then detach (shedding), creating a periodic lift force perpendicular to the flow direction and a periodic drag force aligned with the flow. Both of these forces cause vibrations in the thermowell.

The frequency of vortex-induced vibrations is determined by the shedding frequency, which depends on the diameter of the thermowell and the fluid velocity. The shedding frequency increases linearly with the fluid velocity, but the induced forces increase with the square of the velocity. Consequently, small increases in fluid velocity can generate significantly stronger forces.

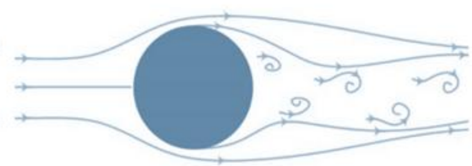
When the shedding frequency approaches the natural frequency of the thermowell, the thermowell may "lock-in" and enter resonance, rapidly increasing the intensity of the vibrations. The longer a body is exposed to vibrations, the more likely it is to fail due to mechanical fatigue. In the case of a thermowell, failure usually occurs at the base, where the bending stress is greatest.

*Laminar Flow*



*Vortex Generation*

*Linear Von Kármán Vortex Street*



*Turbulent Von Kármán Vortex Street*

# FROM BAR OR PIPE?

Thermowells can be machined from solid bar stock or fabricated from pipe.

**Bar-stock Thermowells**

They are made from a solid metal bar that is drilled to the required dimensions, resulting in a robust structure without welded joints. This type of thermowell is ideal for high-pressure and high-temperature applications in environments where mechanical strength, vibration resistance, corrosion resistance, and wear resistance are crucial.

**Pipe Thermowells**

These are made from a section of pipe that is closed and welded at one end, making them less robust than bar-stock thermowells due to the presence of welded joints. They are suitable for low to medium pressure and temperature applications and are commonly used in less demanding environments where extreme durability is not as critical.

The main advantages of choosing pipe thermowells include being less expensive than bar-stock thermowells and easier and quicker to produce, which can be beneficial for large-scale installations. Additionally, they are lighter in weight, making them easier to handle and install.

# MATERIALS

Given that thermowells are designed to protect temperature sensors from extreme and aggressive environmental conditions, the construction material is crucial for their durability and performance. Therefore, the choice of material should be based on a thorough evaluation of operating conditions, chemical compatibility, mechanical properties, safety regulations, and costs. An accurate selection ensures the thermowell longevity and effective protection of the temperature sensor, thereby contributing to the safety and efficiency of the entire industrial process.

When specifying the material, it's important to consider the chemicals, temperature, and flow rate to which the thermowell will be exposed. The corrosive effects of chemicals increase proportionally with their concentration and temperature, and suspended particles in the fluid can cause erosion. Below are some commonly used materials:

**Carbon Steel:** low-cost materials with poor corrosion resistance. Used in low-temperature applications.

**Stainless Steel AISI 304**: corrosion-resistant and low-cost, it is widely used in the processing of food, beverages, and chemicals where good corrosion resistance is required.

**Stainless Steel AISI 316:** offers the best corrosion resistance among austenitic stainless steels, thanks to the addition of molybdenum. Widely used in chemical processes due to its resistance. The **316L** variant has a lower carbon content, enhancing corrosion resistance, and containing more molybdenum.

**Stainless Steel AISI 310:** heat-resistant material that can be used up to 1150°C with useful resistance in sulfur-containing atmospheres. Its corrosion resistance is slightly better than 304SS, but not as good as 316SS. Can be welded with care.

**Stainless Steel AISI 321:** has properties similar to 304SS but is titanium-stabilized to prevent corrosion during welding.

**Stainless Steel AISI 446:** ferritic stainless steel with excellent resistance to sulfurous atmospheres. However, due to its low high-temperature strength, thermowells made from this material should be mounted vertically. Used in heat treatment processes, iron and steel production furnaces, and gas production plants. Provides useful resistance to molten lead.

**Inconel 600:** a widely used nickel-chromium alloy with excellent resistance to high temperatures and oxidation but highly vulnerable to attacks in sulfurous atmospheres above 500°C. Widely used in chemical industries for its strength and corrosion resistance. Easily weldable and can typically be used without post-weld heat treatment.

# MATERIALS

**Inconel 625:** a nickel-chromium alloy with excellent resistance to pitting and crevice corrosion, unaffected by radiation embrittlement. Widely used in aerospace applications and marine environments. It can be used in the welded condition.

**Alloy 825:** a nickel-chromium-iron alloy enhanced with titanium, offering exceptional corrosion resistance in the most aggressive environments. It withstands reducing acids such as sulfuric and phosphoric acid, various oxidizing substances like nitric acid and nitrates, and is also resistant to intergranular attacks..

**Monel 400:** a nickel-copper alloy with excellent corrosion resistance, commonly used for seawater applications, hydrofluoric acid, sulfuric acid, hydrochloric acid, and most alkalis. Typical applications include marine equipment, chemical processing equipment, gasoline and freshwater tanks, process vessels and piping and boiler feedwater heaters.

**Monel K-500:** This nickel-copper alloy is precipitation-hardenable thanks to the additions of aluminum and titanium. It combines the corrosion resistance of Monel 400 with the added advantage of greater strength and hardness, due to its aging hardening capability

**Hastelloy C276:** a nickel-molybdenum-chromium alloy with excellent corrosion resistance, particularly in chlorinated environments. Widely used in chemical plants, it tolerates ferric and cupric chlorides, solvents, chlorine, formic acid, acetic acid, brine, wet chlorine gas, and hypochlorite. It can be easily welded and retains its properties in the welded state.

**Titanium:** a lightweight material with good resistance in the range of 150 to 470°C. It offers excellent resistance to oxidizing acids like nitric or chromic acid, and it is also resistant to inorganic chloride solutions, chlorinated organic compounds, and wet chlorine gas. Its high resistance to seawater and salt fog makes it suitable for offshore installations. Titanium can be welded with special precautions to protect it from atmospheric contamination.

# COATINGS

Coating a thermowell with another material has various purposes and advantages, depending on the specific needs of the application.

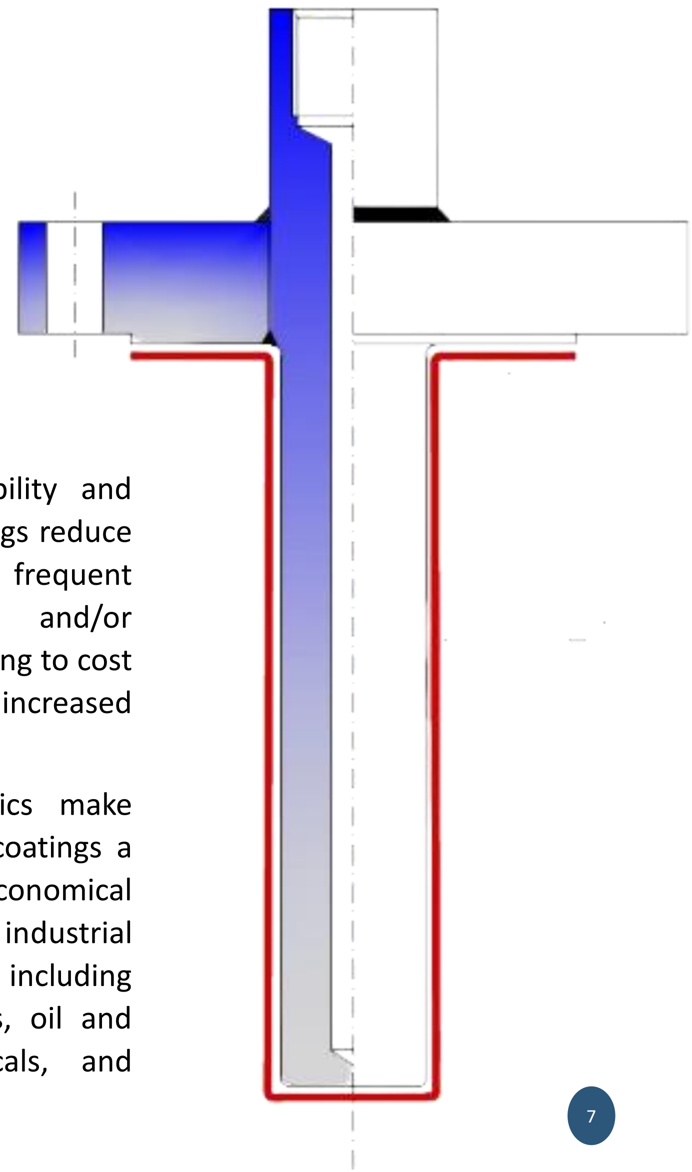
**Corrosion resistance:** a coating can protect the thermowell from the action of corrosive fluids, extending its lifespan and ensuring accurate and reliable measurement over time. Tantalum, for example, is used for its excellent corrosion resistance; it can withstand aggressive chemicals, including hot acids and chlorinated compounds, making it ideal for harsh industrial environments.

**Wear resistance**: coatings with materials such as tantalum or Stellite, a cobalt alloy, offer additional protection against erosion caused by fluid flow, abrasive particles, or other severe conditions. This is particularly important in high-speed applications or with fluids loaded with solid particles.

**High-temperature protection:** some coatings, such as those in Inconel or ceramic, help protect the thermowell and the sensor from high temperatures, maintaining their mechanical and chemical properties in extremely hot environments.

**Chemical compatibility:** a coating with materials like PTFE can ensure that the thermowell does not chemically react with the process fluid, avoiding contamination and ensuring the purity of the final product..

**Ease of Cleaning and Sanitization:** smooth coatings like PTFE are used in industries such as food and pharmaceuticals, where easy cleaning and sanitization are necessary to prevent contamination and ensure high hygiene standards.



The greater durability and resistance of coatings reduce the need for frequent maintenance and/or replacements, leading to cost savings and increased efficiency.

These characteristics make thermowells with coatings a robust and economical solution for various industrial applications, including chemical processes, oil and gas, pharmaceuticals, and more.

# DESIGN

The design of the shank, the portion of the thermowell that is inserted into the process, affects its performance and ease of installation.

**Straight Stem**

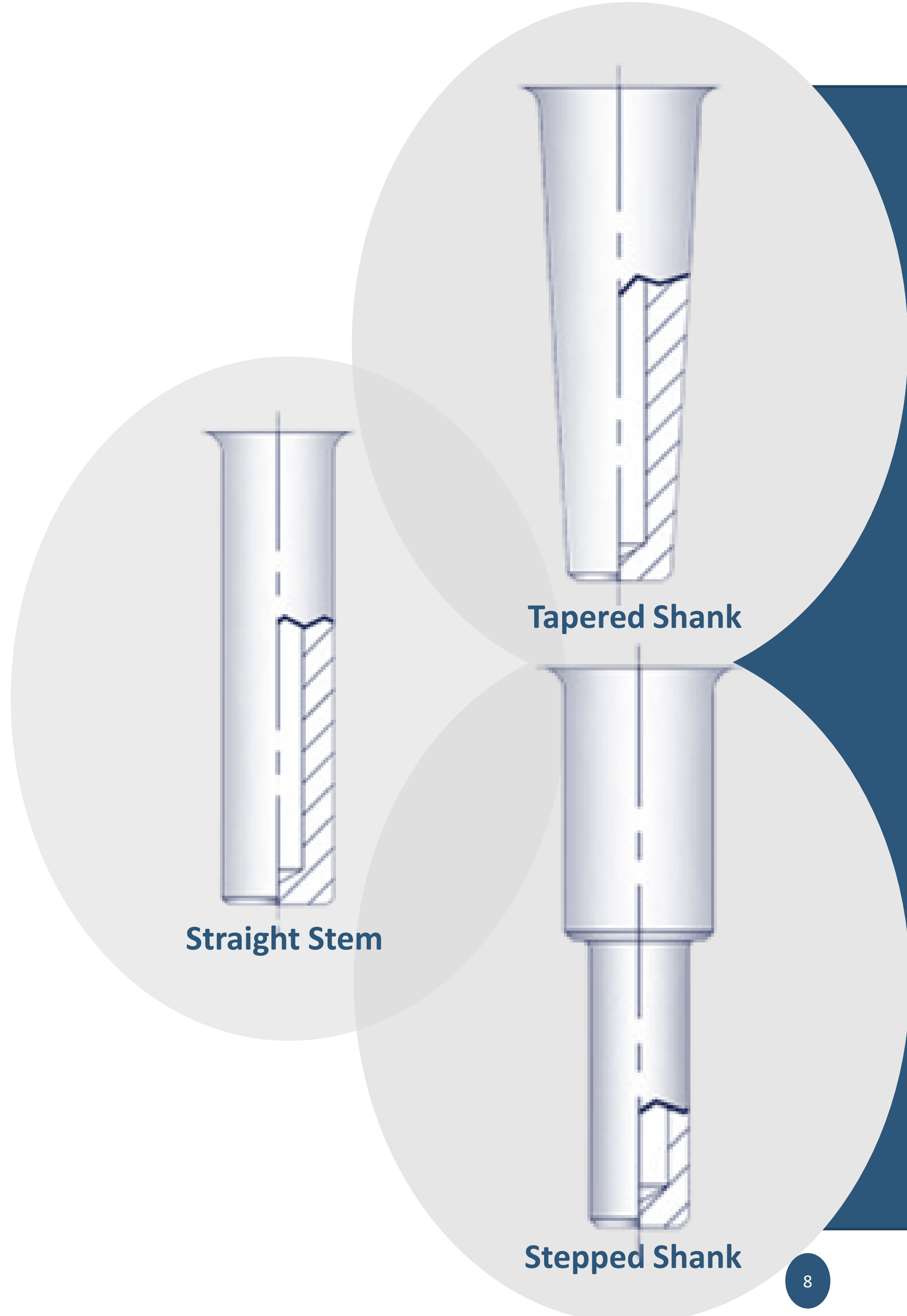
This is the simplest form and is used in applications where there are no special requirements for space or orientation. In this type of thermowell, the shank has a uniform cylindrical shape with the same outer diameter from the root to the tip. Simple and robust, it is suitable for general applications.

**Tapered Stem**

This is the most common type of thermowell; the outer diameter decreases progressively from the root (near the connection) to the tip as the insertion length increases. Compared to the straight stem, it offers better thermal response and reduces fluid flow resistance, making it ideal for applications requiring a quick response to temperature changes.

**Stepped Stem**

Stepped stem thermowells feature a reduction from a larger outer diameter at the root to a smaller outer diameter at the tip, combining the advantages of both straight and tapered stems. For these reasons, they are often used in industrial applications where both robustness and rapid thermal response are required.

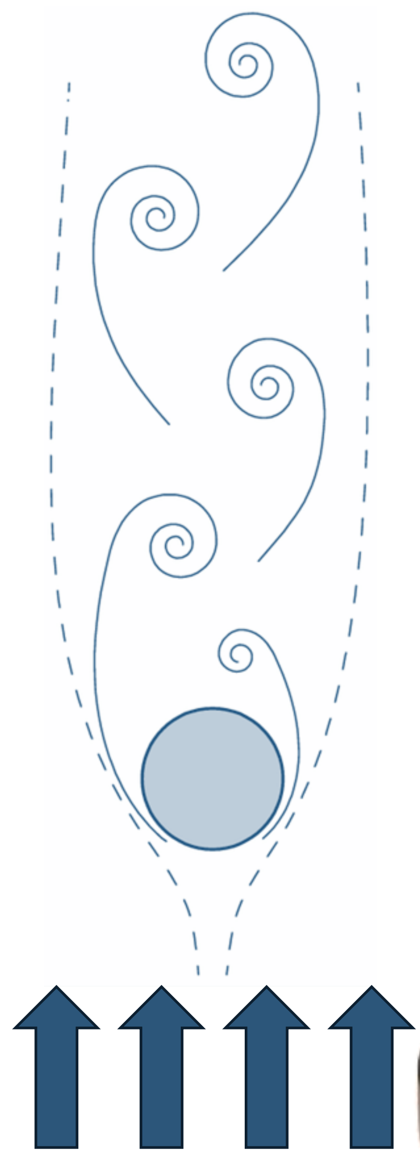


# DESIGN

**Helical Thermowells**

When a thermowell is installed in moving liquid or gas, the inserted stem can cause the formation of a Kármán vortex street. As these vortices resonate with the thermowell, they can damage the stability and integrity of the instrument or the installation. Helical thermowells are specially designed with features that allow them to be well-supported within a fluid flow. The special feature of this type of thermowell is the helical ridges which reduce the formation of vortices within the fluid flow. The advantages include:

- Reduction of effects caused by vortex formation
- Greater durability compared to standard construction
- Ability to accommodate longer insertion lengths with the same diameter
- No need for support collars
- Easy and quick installation
- Suitable for high flow rates and small nozzle sizes
- Better response time compared to conventional thermowells



# PROCESS CONNECTION

Thermowells can be connected to the process in various ways, each designed for specific installation and safety requirements. Here are the main types of connection:

**Threaded Connection**

Uses standard threads to connect the thermowell to the process system. The compact shape of the threaded connection saves space and is also very easy to install. Common in general applications where a quick and secure connection is required for low and medium pressure applications.

**Welded Connection**

The thermowell is welded directly to the process pipe or vessel. This type of connection is ideal for high pressure applications or where a leak-tight seal is required.

**Flanged Connection**

The thermowell is equipped with a flange that is screwed onto a corresponding flange on the process system, which is usually installed on a nozzle or T-fitting connected to the piping or tank.

This type of connection is used in high-pressure applications where a secure and stable connection is required.

Flanges are available in various sizes, designs and pressure ratings.

•FF flanges: these are typically used when the mating flange is made from a casting.

•RF flanges: these are more common in process plant applications. The raised face has a structure suitable for gripping the gasket that is positioned between the two flanges.

•Ring joint flanges: these are used in high-pressure and/or high-temperature applications. This flange has a groove that accepts a metal ring gasket which, once the bolts are tightened, provides a metal-to-metal seal.

Depending on the requirements of use, the flange can be welded to the well with the following designs:

•Screw-welded

•Double welding

•Full penetration welding

# PROCESS CONNECTION

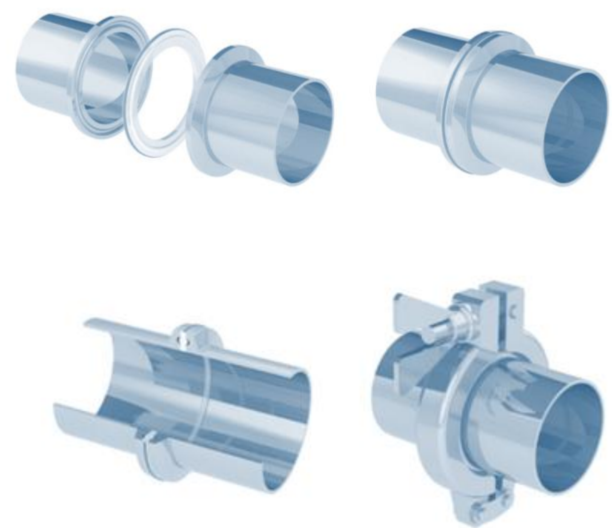
## Van Stone Thermowells

These thermowells are machined from solid bar stock and are mounted between mating flanges for insertion into the process. This type of thermowell is used in applications with high process requirements, such as in the Oil & Gas and petrochemical sectors. This design offers two main advantages:

- Eliminates any stress on the weld.
- The slip-on flange, not being exposed to process conditions, can be made from a less expensive material.

## Thermowells for Sanitary Applications

Sanitary thermowells are typically used in situations where exposed threads could collect contaminants, such as in the food and beverage production or pharmaceutical industry. These thermowells allow the removal of the temperature measuring instrument without losing pressure or process content. They feature a smooth surface and a Tri-Clamp connection, which allows for easy cleaning to prevent process contamination.



# CRITICAL SIZES

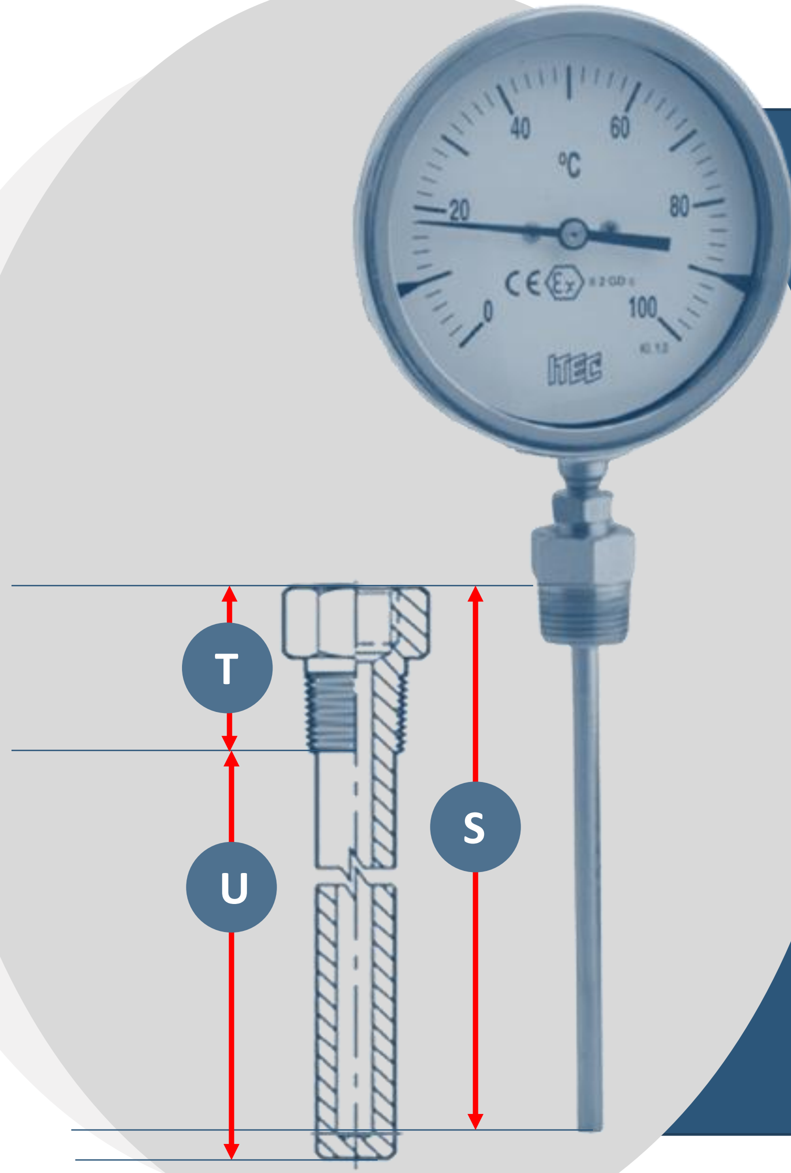
**Process Connection Size:** this is the size of the part of the thermowell that connects to the vessel or pipe. It can be a thread, flange, tube, Tri-clamp, etc.

**Immersion Length (U):** this is the length of the shank portion from the process connection (the lower side of the threading) to the tip of the shank inserted into the process area. To obtain an accurate reading, it is important to fully immerse the sensitive portion of the bulb in the fluid.

**Lag Extension (T)**: indicated as "T" in technical drawings, if applicable. It is used when the vessel or pipe in which the thermowell is inserted is insulated. It represents the additional length between the process connection and the instrument connection of a thermowell, determined by the thickness of the insulation.

**Insertion Length (S):** this corresponds to the total length of the shank to be inserted into the thermowell, from the thread of the instrument connection fitting to the bottom of the shank. Although it is a specification of the measuring instrument and not of the thermowell, it is essential to ensure the correct matching of the thermowell to the instrument stem.

**Internal Diameter (Bore):** this is the internal cylindrical diameter of a thermowell, sized to accommodate the shank or bulb of the measuring instruments. This dimension can be critical as the tolerance must allow for easy installation of the instrument while providing a fit tight enough to minimize thermal lag.



# THERMOWELL CALCULATION

When a thermowell is put into service, it is subject to various stresses typically caused by the movement of the process fluid around the thermowell, which induces both inline and transverse vibrations. These vibrations can lead to mechanical failure of the thermowell. Such a failure can not only result in the loss of measurement but also cause significant damage to expensive equipment and pose a serious safety risk to plant personnel.

While in the past the design of thermowells was primarily based on experience, today the dimensions are calculated based on process data. The importance of proper design based on structural calculations is easily understood by recalling the catastrophic incident in 1995 at the Monju nuclear power plant in Japan, where a thermowell failure occurred despite having previously passed the ASME PTC calculation, leading to a subsequent revision of the standard.

There are several methods for performing structural calculations for a specific thermowell design. The most widely used global standard for the structural calculation of thermowells is ASME PTC 19.3 TW. Another calculation system in accordance with ASME PCT 19.3 is based on principles established by J.W. Murdock in 1959. Additionally, "Stress Analysis of Thermowell" by John E. Brock (1974) and simulations using finite element methods are other possible calculation bases.

Sometimes, according to calculations, a thermowell may not be able to withstand the operating conditions for which it was designed.

In such cases, it may be necessary to modify its geometry, for example, by adjusting the width or length, using a collar, or altering its shape to a helical shank design.

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**THERMOWELL STRESS CALCULATION**

ACCORDING TO ASME PTC-19.3 2016

| DATE | TAG | P.O. NO: |
|---|---|---|
| 20/12/2024 | 5-368B-TW-074_A | |

**FLUID PROPERTIES**

| | |
|---|---|
| Pressure: | 63.8 barG |
| Temperature: | 42 °C |
| Velocity: | 8.9 m/s |
| Density: | 59.22 kg/m³ |
| Viscosity: | 0.0139 cP |

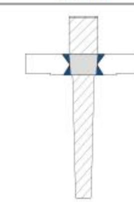
**FLANGE PROPERTIES**

| | |
|---|---|
| Material: | INCONEL 625 |
| Size: | 2" ASME B16.5 CL 1500 RTJ |

**THERMOWELL PROPERTIES**

| | |
|---|---|
| Material: | INCONEL 625 |
| Density: | 8440 kg/m³ |
| Young modulus: | 205866.6666666666 MPa |
| Root Diameter: | 30 mm |
| Tip Diameter: | 30 mm |
| Internal Diameter: | 6.6 mm |
| Unsupp. Length: | 329 mm |
| Nozzle Height: | 245 mm |
| Min. Thickness: | 11.7 mm |

**SKETCH**



FULL PENETRATION

**TEST RESULTS**

| | |
|---|---|
| **Steady-State Stress Test** | PASS |
| Von Mises Stress: | 10.59 bar |
| Stress Limit: | 2747.81 bar |
| **Dynamic Stress Test** | PASS |
| Drag and Lifst Stress: | 16.5 bar |
| Stress Limit: | 624.56 bar |
| **Cyclic Test** | SKIP (1) |
| Scruton Number: | 0.669 |
| Reynolds Number: | 1137535.3 |
| **Pressure Test** | PASS |
| Operating Pressure: | 63.8 bar |
| Min. External Pressure: | 921.08 bar |
| **Wake Frequency Test** | PASS |
| Strouhal Frequency: | 65.27 Hz |
| Natural Frequency: | 180.64 Hz |
| Frequency Ratio: | 0.361 < 0.4 |

**Notes:**

(1) No need to be computed because frequency ratio is below 0.4.(1) No need to be computed because frequency ratio is below 0.4.

(2) No need to be computed because Scruton number is greater than 2.5 and Reynolds number is less then 100000 (low density gases).

Itec has made every reasonable attempt to validate the calculation procedure contained in this file, however, responsability for validation rests solely with the user.

...measuring with you

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# TEST

The resonance frequency calculation described above is generally a prerequisite in the design and drafting phase of a thermowell; however, there are other tests that can be conducted to verify the quality of the product and its execution, such as:

**Hydrostatic test:** this is a pressure and resistance test on the components of a well, during which the thermowell is secured to special testing equipment and subjected to a defined pressure for a specific duration at room temperature. In general, a distinction is made between external and internal pressure tests. Typical test pressure values are 1.5 times the nominal flange pressure for external pressure, or 500 bar for internal pressure.

**Helium leak test:** leak test for thermowells, welds and threaded joints. Depending on the type and size, the thermowell can be subjected to helium gas both internally and externally. This test can detect minimal leak rates and is considered the most sensitive test method for checking leaks.

**Positive material identification (PMI) :** The PMI test verifies which alloy constituents are present in the material. There are several common procedures for this test. With optical emission spectrometry (OES) in accordance with DIN 51008-1 and -2, an arc is generated between the surface of the crucible or protection tube and the test equipment, and the spectrum of this arc allows the alloy elements to be identified both qualitatively and quantitatively.

A distinctive feature of this process is the burn mark left on the piece. One non-destructive testing method is X-ray analysis; during X-ray analysis, the atoms in the material of the well or protective tube are energized until they emit radiation. The wavelength and intensity of the emitted radiation can be used to determine the constituent elements of the alloy and their concentrations.

**Penetrant testing:** this test can detect surface microcracks and porosity in welds. After cleaning the surface to be inspected, a spray with a contrast agent (red or fluorescent) is applied. Thanks to the capillary effect, this agent penetrates any surface defects. The surface is then cleaned again and a spray containing a developer is applied, which extracts the contrast agent from the defects (such as microcracks, etc.) and, thanks to the color contrast, allows for easy evaluation of the defects.

**Ultrasonic testing:** using an ultrasonic test in accordance with DIN EN ISO 17640, for example, full penetration welds on manhole covers can be examined for irregularities (cracks, voids, insufficient adhesion). To do this, the reflections of an ultrasonic signal emitted from the interfaces of the irregularities are measured. To determine the position of the irregularities, the ultrasonic machine is calibrated in advance with the aid of a reference body. In addition, the ultrasonic method can be used to measure the wall thickness of a manhole in order to check the centricity of the hole.

# CONCLUSIONS

At first glance, a thermowell may seem like the simplest and least critical component in a temperature measurement process, serving mainly to protect the sensor from damage; however, in many cases, it is the thermowell that has the greatest impact on the overall efficiency of the temperature measurement system.

Our technical service can provide all the necessary explanations about the materials to be used and the design of the most suitable well for your process, as well as perform calculations in accordance with ASME PTC 19.3 and certify its compliance with the operating conditions of the plant.

**For further information,**

**please do not hesitate to contact us!**

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