Baker Hughes

White Paper

Best Under Pressure

Designing PRVs for Cryogenic Optimization

Executive Summary

Pressure Relief Valves (PRVs) are a necessary requirement for overpressure protection within the LNG industry. However, not all PRVs are created equally when it comes to performance within cryogenic applications, and design temperatures as low as -320°F (-196°C). These applications require PRVs with enhanced sealing features to address the cryogenic conditions and perform their safety function 'Best Under Pressure'.

PRVs are the last line of defense to protect equipment and personnel from an overpressure event. Materials of construction, trim designs and anti-galling measures are all critical for design to address these challenging applications. Common PRV problems in these applications that need to be addressed include:

- **Seat Leakage** Thermal stress from low temperature causes material deflection. This deflection on a seating surface can result in leakage while the valve is closed, or immediately following a relief event.

- **Galling of bearing/guiding surfaces** Anti-seize grease, commonly used in non-cryogenic applications to prevent galling, quickly deteriorates under cryogenic temperatures. This results in galling-induced wear between the metallic components, which leads to seat leakage, valve simmer and 'hang-up' of guiding surfaces as the valve attempts to reseat following a relief event.

- **Process Loss & Fugitive Emissions** Seat damage as a result of prolonged seat leakage, premature opening as a result of major seat leakage, or the PRV not fully closing after a relief event due to excessive galling can all lead to unwanted and costly release, or fugitive emission, of process fluid (Figure 1).

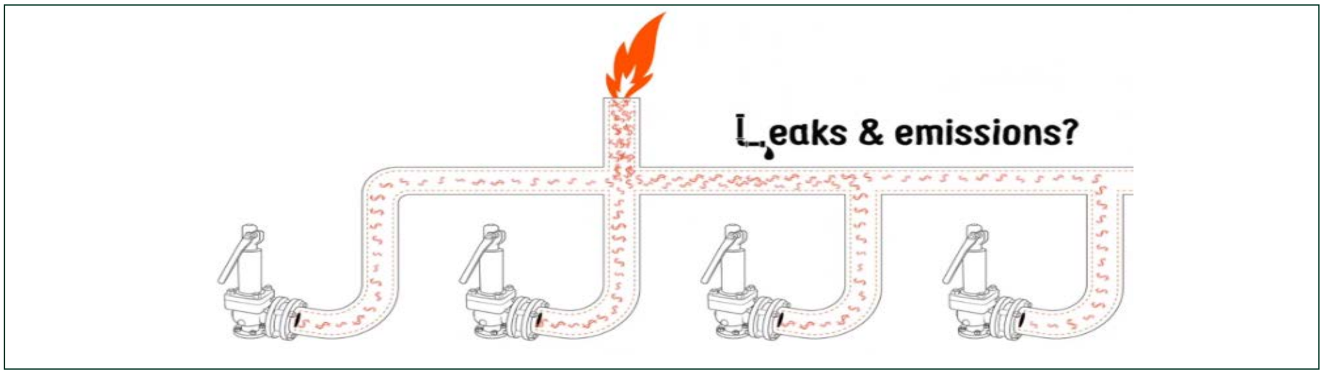


Figure 1 – PRV Seat Leakage Causes Process Loss and Fugitive Emissions

End Users have been implementing local fixes to reduce, or delay, impact to their operation through reactive PRV maintenance. However, severity of cryogenic requirements in the LNG industry extend further than typical relief valve countermeasures that are commonly used today. This paper outlines engineering best practices used today to optimize the design of PRVs used under cryogenic conditions as a "Best Under Pressure" solution specific to LNG critical application needs.

Reactive PRV Maintenance

The traditional approach to managing PRV field issues has been a "good enough" strategy of reactive maintenance. With reactive maintenance, most PRVs follow a regular service interval ranging between every 6 months to every 3 years, set by local site policies and best practices. While this approach may serve to maintain operations, it doesn't always properly analyze root cause failure modes and implement full corrective actions. Unfortunately, this approach has drawbacks due to the unpredictable nature of system operation and PRV performance status after a relief event.

Unplanned Outages

Under long-term harsh conditions, it is difficult to predict with certainty if, or when a PRV is going to open, how long it will open, how stable it will perform under the overpressure conditions, and most importantly, will it reclose and be leak-tight afterwards. For these reasons, operators can find their PRVs in an undesirable state leading to unplanned outages for correction. These outages put operators in a major bind and cause entire supply chains to scramble in attempt to source critical service, parts, and/or replacement PRVs to get the system back up and running.

This urgent scenario is NOT a cheap exercise for anyone involved when you consider premium costs including air freight, expedite fees, and overtime labor. Plants would benefit from better utilization of their resources and spending if they could be redeployed for true system corrective maintenance as opposed to high cost expedited repairs.

Maintenance Guesswork

PRV maintenance can be next to impossible to accurately predict. If you ask a PRV manufacturer "How often should I service my PRV?" the answer is resoundingly the same: "It depends…" In their defense, they are not dodging the question, because it truly does depend!

Factors to consider when developing a PRV service interval plan include criticality of the service, how often the PRV is expected to cycle, the amount of debris and particulates in the line, the stability of the PRV during the overpressure event, and countless other variables! As a result, End Users tend to error on the side of caution and service their PRVs more often than required. Operators are too often throwing away precious dollars to service PRVs where, in some cases, do not require service. Better safe than sorry, right?

Innovative Design Solutions

Cryogenic PRV applications require optimized design solutions with countermeasures for seat leakage and galling prevention to address commonly known failures and prevent unplanned downtime, PRV repair and reduced fugitive emissions. Time is money, right? We want to save you time and money by providing the most reliable cryogenic PRV with design features proven and tested.

Failure Mode: Seat Leakage before and/or after a relief event

Design Solution: Enhanced disc designed for high performance under low temperature

Thermal Analysis of Consolidated™ Standard 1900 Series Disc

Standard Disc and Nozzle for a 1905 P Orifice

The typical failure mode of a PRV operating with cryogenic media is seat leakage after valve actuation, or, when the operating pressure is close to set pressure. Once an initial valve seat leak, or simmer, is established, icing can build on the seat causing leakage to progressively worsen as the PRV begins to visually resemble a ball of frost after an extended period of time. These leaks can be stopped when the valve body and inlet flange are heated with an external heating element to eliminate the icing, thus allowing proper reseating.

The Finite Element Analysis (FEA) shown in the following sections has been used to replicate this failure mode. As the process media escapes through a microleak flow path, the fluid undergoes a iso-enthalpic, pressure drop that produces a localized reduction in temperature. Simulations show liquified methane operating at 90% of set pressure, with a fluid temperature of -190ºF (-123.3ºC), yielding a localized temperature reduction as low as -250ºF (-156.6ºC). A thermal FEA was performed to simulate this leak path in a very small area between the nozzle and the disc shown in Figure 2 below. The thermal analysis simulates the temperature profile of a leaking valve, and is the input for performing the static FEA to understand its impact on the seat tightness of the valve. At 90% of set pressure, it was demonstrated that there were no contact forces between the disc and nozzle, not only at the leak path, but also in the area immediately adjacent to the leak path as shown in Figure 3.

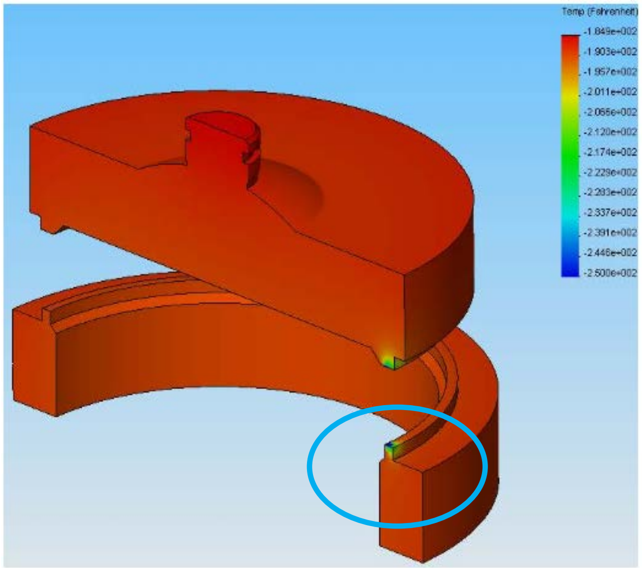


Figure 2 – Temperature Distribution with Leak Path Simulation

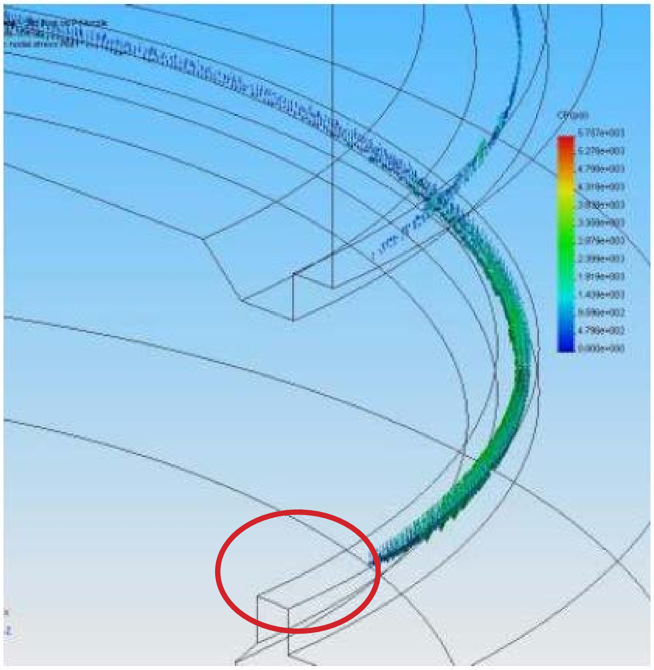


Figure 3– Contact Pressure Distribution, Standard Nozzle and Standard Disc

Innovative Design Concept

The Consolidated *Thermodisc*™ leverages reverse thermal expansion principles as demonstrated over a long 70-year history of successfully proven, leak-tight performance on high temperature gas and steam applications. The innovative thermolip feature in the disc uses the temperature differential between the process fluid and ambient temperature in the body bowl to cause a downward deflection providing more contact stress on the nozzle seat, thus creating greater seat tightness at elevated temperatures. FEA was performed on the Thermodisc using high temperature and cryogenic temperature boundary conditions to analyze the deflection performance. As shown in Figure 4, the deflections due to temperature are different and opposite for high temperature and cryogenic temperature.

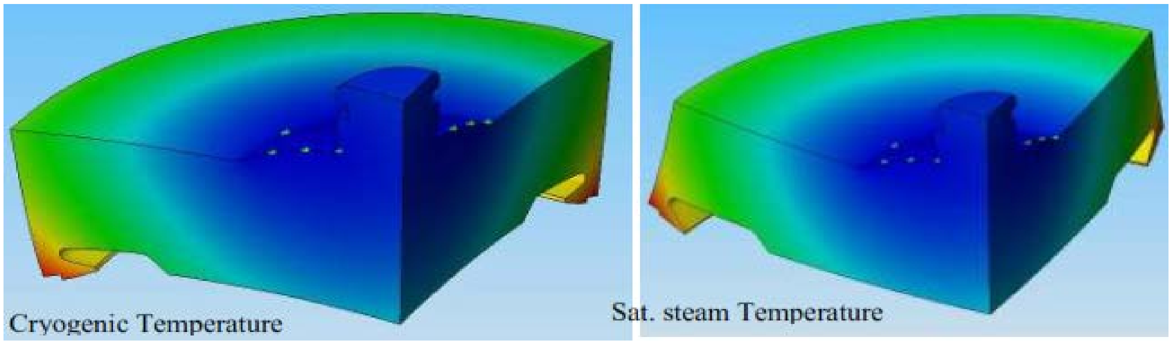
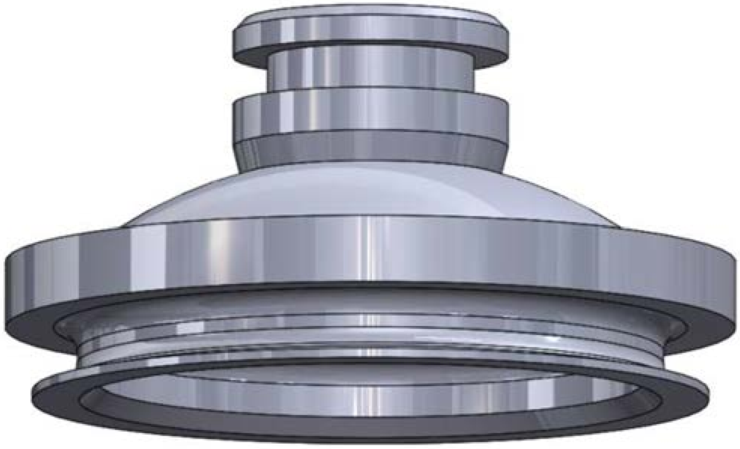


Figure 4 – Deflections of Thermodisc Under Cryogenic and Saturated Steam Conditions.

(deflections magnified for illustration)

The design concept of the Thermodisc uses the differential temperature to provide downward axial deflection. This concept was used to develop the patented reversed thermolip Cryodisc. Thus, producing the same leak tight performance at cryogenic temperature as the proven Thermodisc yields at elevated temperatures.

INTRODUCING:
The Consolidated 1900/1900 DM and 2900 Series Series Patented "Cryodisc" Technology



Cryodisc Thermal Analysis Results

The boundary conditions used for FEA analysis of the Cryodisc are the same conditions as applied to the previously mentioned analysis of the 1905P standard disc and nozzle.

The FEA results shown in Figure 5 demonstrate the disc and nozzle temperatures have reached the full fluid temperature. The plot shows the temperature distribution on the Cryodisc and nozzle components as a leak path is simulated. The analysis shows the temperature drops across the leak path below (Figure 5).

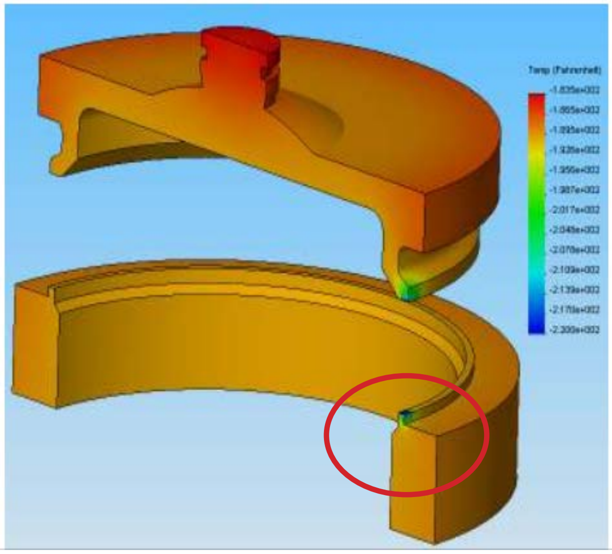


Figure 5 - Temperature Distribution with Leak Path Simulation

Thermal Stress and Contact Analysis

These same loads are used for both the benchmark study and for the standard 1905P disc and nozzle. Figure 6 shows the uniform contact pressure distribution around the seating area between the Cryodisc and the nozzle. The lower the coefficient of thermal expansion, the greater the improved performance of the Cryodisc. The reversed thermolip maintains contact pressure in the leak region even as a microleak develops. Inconel X-750 material was chosen for the Cryodisc's enhanced performance for its low coefficient of thermal expansion, chemical inertness, strength and ductility.

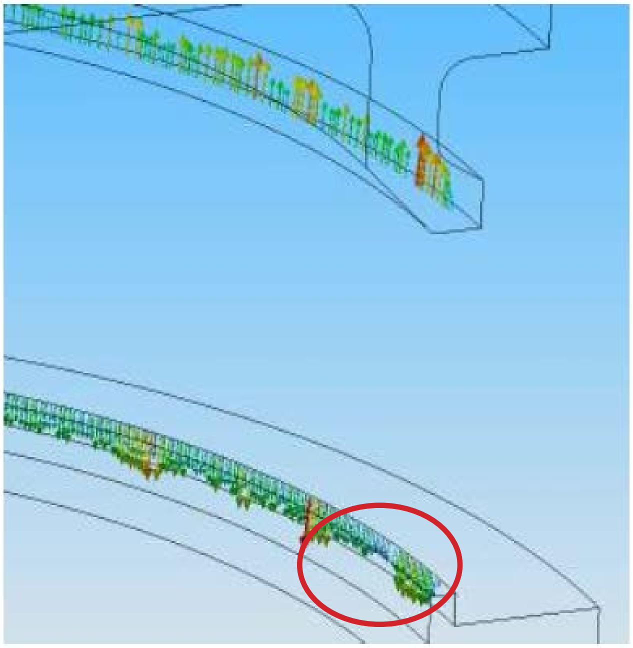
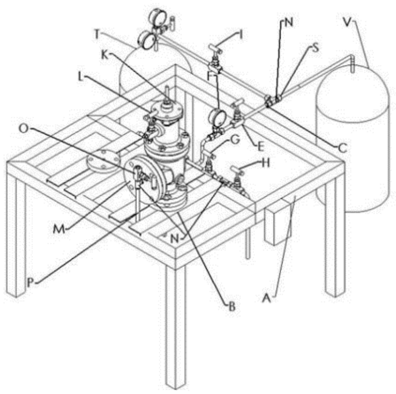


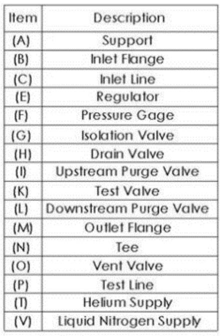
Figure 6 – Contact Pressure Distribution, Cryodisc on Standard Nozzle

1900/1900 DM Cryogenic Valve Testing

Liquid nitrogen was supplied to the 1900/1900 DM nozzle with a cloud of gaseous nitrogen at the disc-seat region. This was done to best represent field conditions where vaporization of the liquid natural gas in the nozzle is expected.

Test Stand Schematic





Item	Description
(A)	Support
(B)	Inlet Flange
(C)	Inlet Line
(E)	Regulator
(F)	Pressure Gage
(G)	Isolation Valve
(H)	Drain Valve
(I)	Upstream Purge Valve
(K)	Test Valve
(L)	Downstream Purge Valve
(M)	Outlet Flange
(N)	Tee
(O)	Vent Valve
(P)	Test Line
(T)	Helium Supply
(V)	Liquid Nitrogen Supply

Verifying FEA Results with Actual Test Results

In order to verify FEA results, actual cryogenic testing using liquid nitrogen with test temperatures down to -320ºF (-196ºC), was performed on 1900/1900 DM Series valves. Pictures shown on page 6 are two 1905 H orifice DM Series valves. One of the valves has a standard disc design, and the other is enhanced with the Cryodisc technology.

The test results summarized in Table 1 below are the average of multiple sizes of F, H and J orifice and tests with a set pressure of 100 psig, not based on single test results.

Table 1: Standard Trim vs. Cryodisc Leak Performance

	Standard Trim			Cryogenic Trim		
	Leak pressure as % set	Time, min	Leak rate, BPM	Leak pressure as % set	Time, min	Leak rate, BPM
1900F/J	90.0%	14	20	90%	15	18
		15	52		24	15
		20	250		46	2

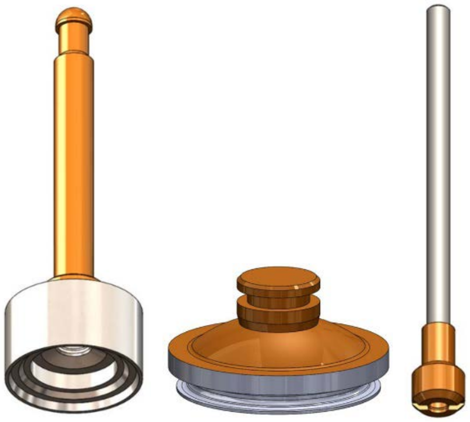
The seat leakage, based on API 527 bubbles/minute criteria, for the standard disc show the leakage rates considerably worsen over time. This quantifies the FEA results of the standard disc showing no contact pressure in the leak path. As the leakage rate worsens over time, plants will experience seat damage, simmer and unwanted fugitive emissions.

Comparably, the seat leakage results using the Cryodisc show the leakage rate improving over time, well within the API 527 acceptable bubbles/minute criteria. Based on test results, the FEA results for the Cryogenic disc can be confirmed that contact pressure increases as the low temperature causes the thermolip to deflect axially downward increasing the contact pressure on the nozzle.

The enhanced seat tightness due to the Cryodisc is proven through FEA and validated through actual lab testing. A PRV that can maintain seat tightness on LNG will save users on unplanned downtime, PRV repair costs, process loss and excessive fugitive emissions. The Consolidated 1900/1900 DM SRV and 2900 Series POSRV with Cryodisc are the clear choice for your cryogenic PRV needs.

Failure Mode: Galling of bearing and guiding surfaces

Design Solution: Titanium Nitride coating



Titanium nitride (TiN) coating is an extremely hard ceramic material (harder than carbide or chrome) applied to improve the substrate's surface properties. It's applied as a thin coating, less than 4µm, and is used to harden and protect metal to metal bearing surfaces, sliding/guiding surfaces and for cutting tools. This coating eliminates galling, microwelding, seizing and adhesive wear on the critical PRV components. It has a very low friction, enhances corrosion resistance and has erosion resistance.

Cryogenic PRV testing was performed at the Houston Advanced Research Center (HARC) with the PRVs submerged in liquid nitrogen. Testing was performed on various sizes and set pressures of the 1900 Series "L3" low temperature (-151ºF (-102ºC) to -450ºF (-268ºC)) material variation valves and it was discovered that after multiple cycles under full cryogenic conditions, the valves exhibited hanging while closing and seat leakage above API 527 allowable leakage rates. During the PRV teardown, galling was noticed on bearing surfaces and guiding surfaces such as spindle to disc holder, disc holder to disc, guide inside diameter and disc holder outside diameter. TiN coating was applied to all bearing surfaces of the bearing components, IDs and ODs of guiding components and repeated cryogenic testing was performed. The tests results showed drastic improvements in seat leakage resulting from the elimination of galling of the bearing and guiding surfaces of these components after cycle testing of the PRVs under these conditions. The valves showed smooth opening and closing, without hanging and with tight shutoff.

Based on these results, TiN coating is now standard on the critical bearing and guiding components of the Consolidated 1900/1900 DM and 2900 Series L3 material variation valves making these PRVs differentiators in the LNG market. A PRV that can maintain seat tightness after a relief event on LNG will save User's on unplanned downtime, PRV repair costs, process loss and excessive fugitive emissions.

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