DESIGN MODIFICATIONS IN CRYOGENIC PRESSURE RELIEF VALVE TO ELIMINATE SEAT LEAKAGE

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Abstract - *Cryoliquids plays vital role in rocket engines, transportation and storage of large masses of frozen food. Storage and transport of cryoliquids of very low temperatures is very difficult. In the pipe lines or the storage facilities that contain this kind of low temperature liquids must be equipped with more safety measure as the expansion ratios of this liquids is very large as 700 times. If this pressure exceeds the limits this may leads to burst in pipe lines. This is where safety pressure relief valve shows its importance. Thermal relief valve is designed to popup for reliving excess pressure from at a predetermined pressure and reseat after reliving the excess pressure from the segment.*

Thermal relief valves provided in most of cryo systems are metal to metal seated for ensuring leak tightness and are sized to relieve minimum flow rate of 300 SCFM of air. For metal to metal seated valves, attaining zero leakage or Class VI leakage classification is not possible due to surface finish limitations.

Studies have been carried out to convert existing metal to metal seated valves to soft seal. To provide soft seal – PCTFE (Polychlrotriflouro ethylene) to suit to existing disc and nozzle configuration. To use the same spring provided for the valve. Force balance and strength calculations for the modified geometry of the disc. Calculation of leakage pressure based on the modified geometry. Followed by experimental tests with air and Liquid Nitrogen. Eventually, more efficient and operational Cryogenic valve with standing more number of pop-ups will be established.

1. INTRODUCTION

Over the years there have been a number of advancements in the Cryogenic and Industrial gas industries with the aim of keeping liquefied gases colder longer. At some point even the best cryogenic storage tanks will experience some heat flux from their surroundings, causing the temperature inside the tank to rise to a point that some of the liquefied gas begins to evaporate and reverts back to its gaseous state. This process is known as Boil-Off Gas (BOG). The use of a safety relief valve specifically designed for cryogenic temperatures is the best choice for handling pressure rise due to BOG. The first of these safety features is typically an ASME certified safety relief valve, which have an operating temperature range of -423°F to +400°F, which also makes them an ideal choice for labs and other facilities where nitrogen and other gases are supplied by boil-off from liquid gas storage tanks.

1.1 Functions of PRV

Every industrial process system is designed to work against a certain maximum pressure and Temperature called its rating or design pressure. The law requires that when everything fails regardless of the built-in redundancies, there is still an independent working device powered only by the medium it protects. This is the function of the PRV, which, when everything else works correctly in the system, should never have to work.

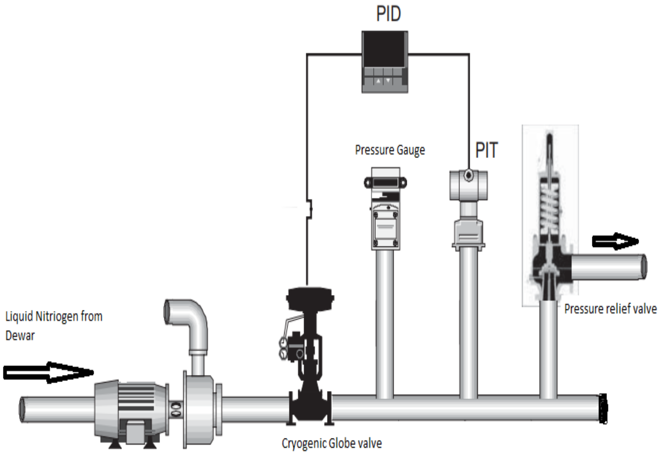


Fig1.1: Traditional control loop

2. THERMAL RELIEF VALVES

2.1 Thermal relief valve - Introduction

Thermal relief valve is a self-actuated spring-loaded relief valve is designed to popup for reliving excess pressure from at a predetermined pressure and reseat after reliving the excess pressure from the segment. The basic elements of a thermal relief valve consist of a nozzle connected to the vessel or system to be protected, a movable disc which controls flow through the nozzle, and a spring which controls the position of the disc. Under normal system operating conditions, the pressure at the nozzle inlet is less than the set pressure and the disc is seated on the nozzle by spring force preventing flow of fluid.

The operation of a thermal relief valve is based on a force balance. The spring-load is present to equal the force exerted on the closed disc by the inlet fluid when the system pressure is at the set pressure of the valve. When the inlet pressure is below the set pressure, the disc remains seated on the nozzle in the closed position. When the inlet pressure exceeds set pressure, the pressure force on the disc overcomes the spring force and the valve opens. When the inlet pressure is reduced to a level below the set pressure, the valve re-closes.

Fig 2.1: Cryogenic PRV in operation at LSSF

2. 2 Thermal relief valves in Cryo systems

In order to meet the requirement of different operating conditions encountered during launch servicing, spring loaded relief valves (Thermal relief valves) are provided in cryo systems for gas/vapor relief and full flow relief valves for the purpose of liquid relief Thermal relief valves provided in cryo systems are installed between two isolation valves to relive excess pressure due to locked up vapors attributing to high volumetric expansion of cryo Liquids.

All the valves are metal to metal seated for ensuring leak tightness and are sized to relieve minimum flow rate of 300 SCFM of air. Following table gives the details of all models of valves provided along with effective orifice areas as per API 520 sizing standard.

Table 2.1: Valve- orifice areas

Sl.no	Model.NO	Orifice area (mm^2)	Rated Flow capacity
	951111MD	0.47	408.1 SCFM of air
	961111MD	0.71	414.1 SCFM of air

2.3 Valve seat leak testing standards

Allowable leakage values are specified in respective API codes –API 527 based on orifice diameter, size of the valve, type of sealing adopted. The following table gives the leakage values provided by API527.

The allowable leakage values for metal to metal seated relief valves. Test medium: Air

Table 2.2: Allowable leakage values

	Manufacturer's orifice area sq.cm	Allowable Bubbles/min
	0.47 and smaller	40
	0.71 and smaller	40
	1.264 and smaller	20

2.4 Acceptance criteria:

The following criteria must be met with, in order to incorporate the modified seat design:

- For metal to metal seated valves tested with GN2/Air, the leakage rate shall not exceed the valves specified in the above table.
- For soft seated valves no bubbles per minute at 90% of set pressure.

2.5 Main reasons of Valve Seat Leakage

1. Improper alignment of subassemblies after testing.
2. Spring buckling resulting in angular misalignment
3. Loose tolerances for spindle at its seating area, clearances between disc holder and disc.
4. Poor Surface finish/wear at metal to metal seat contact area of valve

2.6 Problems faced with metal to metal seated valves:

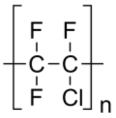
Even though specified leak rate is allowed, due to hazardous nature of cryofluids like hydrogen, no leakage of hydrogen vapors/gases is permitted across the valve during normal operation. For metal to metal seated valves, attaining zero leakage or Class VI leakage classification is not possible due to surface finish limitations.

To meet the leakage classification of ANSI –Class VI, the only option is to provide soft seal across valve seat.

3 SELECTION OF SOFTSEAL

3.1 Polychlorotrifluoroethylene (PCTFE or PTFCE)

Polychlorotrifluoroethylene (PCTFE or PTFCE) is a thermoplastic chlorofluoropolymer with the molecular formula (C2F3Cl)n, where n is the number of monomer units in the polymer molecule. It is similar to polytetrafluoroethene (PTFE), except that it is a homopolymer of the monomer chlorotrifluoroethylene (CTFE) instead of tetrafluoroethene. It has the lowest water vapor transmission rate of any plastic



$$\left[-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{Cl}{C}}- \right]_n$$

Properties of PCTFE

- PCTFE has high tensile strength and good thermal characteristics. It is nonflammable. It has a low coefficient of thermal expansion.
- It has good chemical resistance & exhibits properties like zero moisture absorption and non-wetting.
- PCTFE is resistant to the attack by most chemicals and oxidizing agents.

PCTFE is selected for the following reasons:

1. Has very high compressive strength, flexural rigidity.
2. Better creep resistance, fatigue life compared to PTFE.
3. Can withstand very low temperatures.
4. Very good friction and wear characteristics at low temperatures.
5. Very low deformation at low temperatures
6. Low permeability for gases like N2, O2 and GH2.

4. EXPERIMENTAL SETUP

4.1 Experimental Setup

Experimental setup consists of Liquid nitrogen storage tank (Dewar), Cryogenic globe valve, Pressure gauge, Cryogenic pressure relief valve. The arrangement of these are shown in the following schematic diagram.

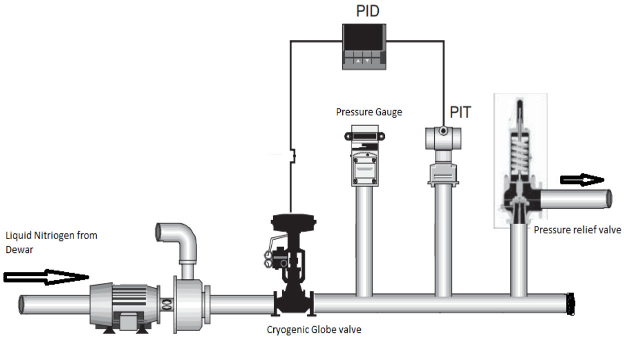


Fig 4.1: Experimental setup schematic representation

Initially the liquid nitrogen which was stored in Dewar was connected to vacuum sealed pipe line and is made flow through the setup as shown above. This liquid nitrogen initially flown through the cryogenic globe valve which is in open condition. Pressure gauge was connected to the pipe line so that the pressure in the pipe line can be noticed. To observe the performance of the Pressure relief valve it is connected to the pipe line and the flow is restricted after the attachment of Pressure relief valve to the pipe line. As pipe line was closed at the end, pressure will build up inside the pipe line over the time. When the pressure inside the pipe line reaches the set pressure of the cryogenic pressure relief valve, it will relieve the excess pressure inside the pipe line by popping up the excessive liquid inside the pipe line so that the normal predetermined pressure is maintained.

4.2 Dewar

Cryogenic Vessels are designed for storage and transport of liquid gases at sub-zero temperatures.

Fig 4.2: Liquid nitrogen storage tank at operation

4.3 Cryogenic Globe Valve

Cryogenic globe valve used to regulate the flow direction, flow rate of the fluid flows through the pipe line.

Fig 4.3: Cryogenic globe valve

4.4 Pressure gauge:

This device used in the setup to know the pressure inside the pipe line and also examine whether the valve pop-up at the set pressure or not.

Fig 5.4: Pressure Gauge – Globe valve setup

4.5 Cryogenic Pressure relief valve

These are used to relieve the excess pressure inside the pipeline.

Fig 4.5: Cryogenic pressure relief valve

5 MODIFICATIONS CARRIED OUT

5.1 Modification carried out:

To incorporate PCTFE seal in to nozzle disc contact area, the disc is modified and soft seal is assembled in to disc with interference fit so that the seal does not come out in case of valve pop up.

5.2 Design

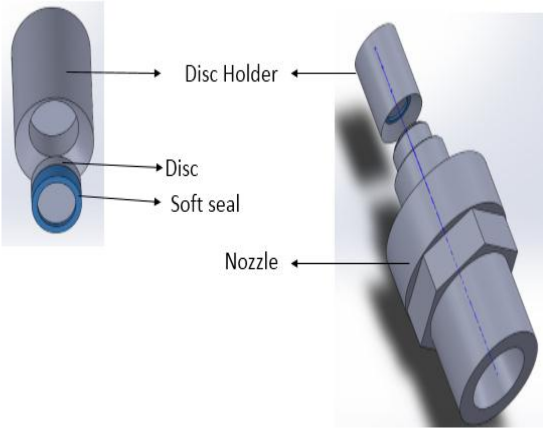


Fig 5.1: Metal disc with disc holder and nozzle assembly

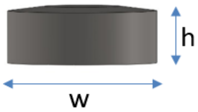
5.2 Disc

The disc is made of forged bar stock as per ASTM A479 SS316 for low temperature compatibility.

5.3 Soft Seal

The soft seal is made out PCTFE.

Metal disc



S.no	Description	Disc = Metal	
		951111MD	961111MD
1.	Height - h (mm)	5	7.5
2.	Width - w (mm)	11.9	14.5

Fig 5.2: Metal disc

Table-5.1: Metal disc - Dimensions

Disc with Soft seal

S.no	Description	Disc = Metal + Soft seal	
		951111MD	961111MD
1.	Height - h (mm)	5.4	7.8
2.	Width - w (mm)	12	14.5

Fig 5.3: Metal disc with sealing

Table 5.2: Soft seal – Dimensions

5.4 Nozzle

The same nozzle provided for metal to metal seated valves is used for soft seated valves also.

- Model: 951111MD-Orifice Size as per API: 8.33mm
- Model: 961111MD-Orifice Size as per API: 10.12mm

5.5 Spring

The spring selected is same as that used for metal to metal seated safety valve having the same spring range, Spring Index are calculated as given in Table.

Table5.3: Spring data

Spring Data		Units	951111MD	961111MD
Tag No.			VST - 4700	VST – 720,721
Range		PSIG	248 - 274	195 - 216
		MP$_a$	1.709 - 1.889	1.344 – 1.489
Material			SS316	SS316
Mean Diameter	D_m	mm	24.61	30.3
Wire Diameter	d	mm	4.35	4.8
Spring index	I		5.65	6.31
Modulus of Rigidity	G	N/mm^2	82000	820000
Number of active coils	W_c		6	8
Solid length	L_s	mm	26.1	38.4
Spring constant	k	N/mm	41.03	24.44

6. DESIGN CALCULATIONS

The movement of the disc depends on the force balance between the upward fluid force, F_{up} and the downward spring force and back pressure forces F_B [13]

1. Fluid pressure force.
2. Spring force.
3. Reaction force on the disk contact area.
4. Body force (disc).

6.1 Pressure Distribution on PCTFE Seal in Static condition [2]:

The average pressure acting on the seat area:

P1= Static Pressure at the inlet condition $\acute{P} = \frac{2}{3} P_1$

For 951111MD: $Pavg = \frac{2}{3} * 16 = 10.666$ bar

For 961111MD: $Pavg = \frac{2}{3} * 11 = 7.333$ bar

However for seal design purposes, the maximum operating fluid pressure is considered.

Sn	Description		units	Safety valve model	
a	**Spring Data**			**951111MD**	**961111MD**
1	Mean Diameter	Dm	mm	24.61	30.3
2	Wire Diameter	d	mm	4.35	4.8
3	Modulus of rigidity	G	N/mm^2	82000	82000
4	No of active coils	Wc		6	8
5	Free Length	Lf	mm	50	76
6	Solid Length	Ls	mm	26.1	38.4
7	Spring rate	k	N/mm	41.038	24.44
8	Spring Initial Compression required		mm	5.8	9.12
9	Assembled Load	Fa	N	238.02	222.97
10	Assembled length	La	mm	44.2	66.88
b.	**Fluid Pressure Load**	**P**	**N/mm^2**	**1.6**	**1.1**
1	Outer Diameter	do	mm	12	14.5
2	Inner Diameter	di	mm	9.3	11.5
3	Seat Land width	ds	mm	1.35	1.5
4	Effective seat diameter (2/3 rd of seat Land diameter)	deff	mm	11.1	13.5
5	Disc effective contact area	Ae	mm^2	28.843	39.275
6	Fluid Pressure Load	Fp	N	46.149	43.202
7	Net Sealing Load	Fn	N	191.87	179.78
8	Seal Land width	w	mm	1.35	1.5
9	Seal Sealing Area	As	mm^2	50.900	68.338
10	Sealing Stress Induced in PCTFE Seal for provided land width	S	N/mm2	3.7696	2.630

Table 6.1: Seating stress calculation

This Seating stress is sufficient for PCTFE to seal at the above spring assembled Load for normal operating conditions.

6.2 Study of dynamic Force Balance during valve lift at various flow deflection angles [11]

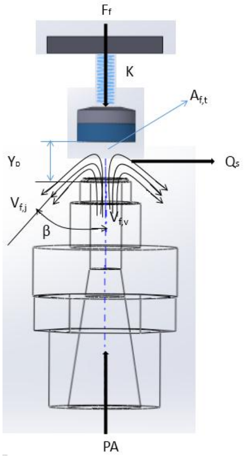
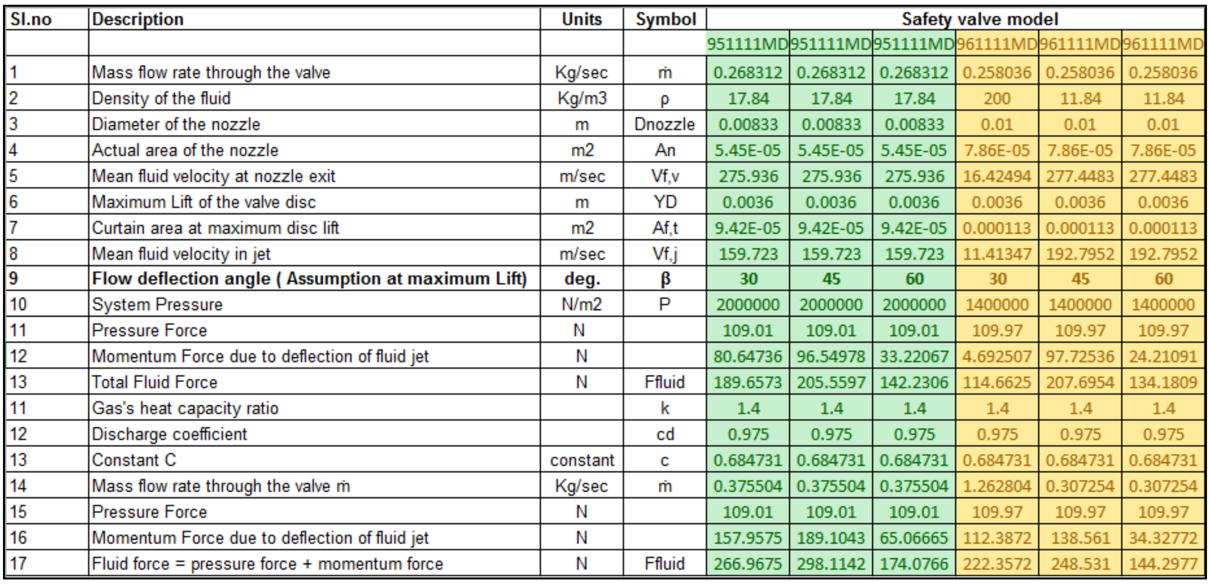


Fig 6.1: Different forces acting at the opening condition of valve

When the fluid pressure reaches the set value, the disc loses contact with the seat and starts lifting against spring force.

Table 6.2: Dynamic force calculation



Sl.no	Description	Units	Symbol	Safety valve model					
				951111MD	951111MD	951111MD	961111MD	961111MD	961111MD
1	Mass flow rate through the valve	Kg/sec	ṁ	0.268312	0.268312	0.268312	0.258036	0.258036	0.258036
2	Density of the fluid	Kg/m3	ρ	17.84	17.84	17.84	200	11.84	11.84
3	Diameter of the nozzle	m	Dnozzle	0.00833	0.00833	0.00833	0.01	0.01	0.01
4	Actual area of the nozzle	m2	An	5.45E-05	5.45E-05	5.45E-05	7.86E-05	7.86E-05	7.86E-05
5	Mean fluid velocity at nozzle exit	m/sec	Vf,v	275.936	275.936	275.936	16.42494	277.4483	277.4483
6	Maximum Lift of the valve disc	m	YD	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
7	Curtain area at maximum disc lift	m2	Af,t	9.42E-05	9.42E-05	9.42E-05	0.000113	0.000113	0.000113
8	Mean fluid velocity in jet	m/sec	Vf,j	159.723	159.723	159.723	11.41347	192.7952	192.7952
9	**Flow deflection angle (Assumption at maximum Lift)**	**deg.**	**β**	**30**	**45**	**60**	**30**	**45**	**60**
10	System Pressure	N/m2	P	2000000	2000000	2000000	1400000	1400000	1400000
11	Pressure Force	N		109.01	109.01	109.01	109.97	109.97	109.97
12	Momentum Force due to deflection of fluid jet	N		80.64736	96.54978	33.22067	4.692507	97.72536	24.21091
13	Total Fluid Force	N	Ffluid	189.6573	205.5597	142.2306	114.6625	207.6954	134.1809
11	Gas's heat capacity ratio		k	1.4	1.4	1.4	1.4	1.4	1.4
12	Discharge coefficient		cd	0.975	0.975	0.975	0.975	0.975	0.975
13	Constant C	constant	c	0.684731	0.684731	0.684731	0.684731	0.684731	0.684731
14	Mass flow rate through the valve ṁ	Kg/sec	ṁ	0.375504	0.375504	0.375504	1.262804	0.307254	0.307254
15	Pressure Force	N		109.01	109.01	109.01	109.97	109.97	109.97
16	Momentum Force due to deflection of fluid jet	N		157.9575	189.1043	65.06665	112.3872	138.561	34.32772
17	Fluid force = pressure force + momentum force	N	Ffluid	266.9675	298.1142	174.0766	222.3572	248.531	144.2977

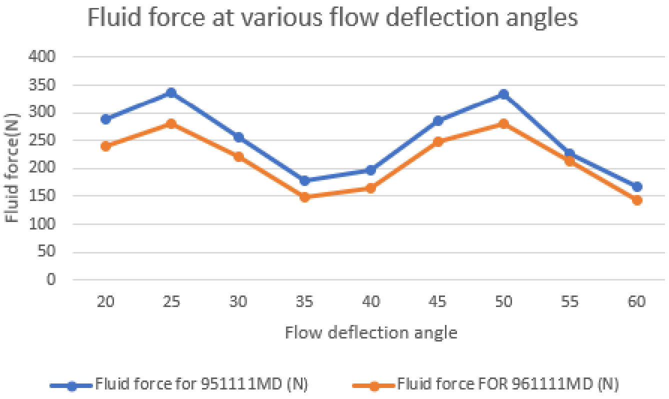


Fig 6.2: Fluid force at various deflection angles

From above the observation is made such that as the Flow deflection angle is increasing the fluid force is decreasing, which is a welcome note because usually the flow deflection angle is greater than 45 degrees which means the momentum force acting on the disc is in the acceptable region.

7 LIFTING PRESSURE CALCULATIONS

F is the applied load or the spring force at equilibrium condition and φ is the angle in case of misalignment of the applied load. [2]

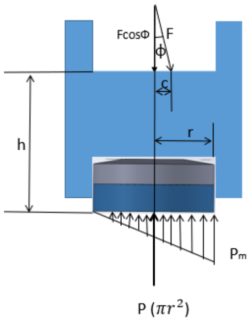


Fig 7.1: valve leakage analysis

Table7.1: Leak pressure calculations

Sn	Description		Units	951111MD	961111MD
1	Distance of disc from Load application point	h	mm	7.76	7.76
2	Applied load (Due to Spring)	F_a	N	238.0251	222.979
3	Safety valve Set pressure	P	N/mm^2	2.2	1.375
4	Disc radius	r	mm	6	7.25
5	Distance from centre axis to applied load	c	N	0	0
6	Angle of the applied load	ϕ	Deg	0	0
7	Frictional Forces	F_f	N	0	0
8	Maximum force acting on sealing surface of disc	$F= F_a$	N	238.0251	222.973
9	Pressure at which disc starts Lifting	P_{lift}	N/mm^2	2.105672	1.3514

From the above table we can conclude that the Lifting pressure calculated matches to the set pressure of the disc. This means the PCTFE Sealing disc works in a desirable way and gives the best results.

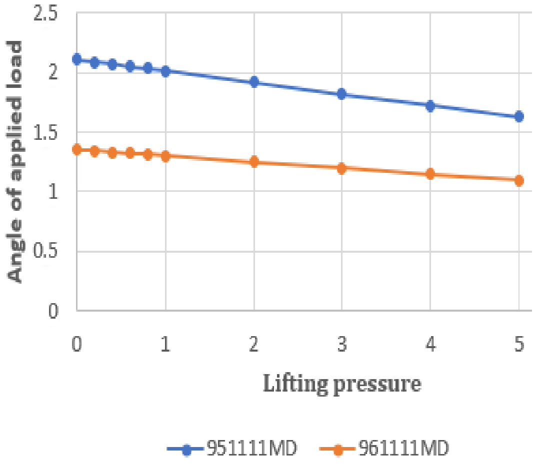


Fig 7.2: Lifting pressure at various applied loads

the above chart represents considering the misalignment of the application of load which further calculated for the pressure at which valve disc starts lifting.

8 LEAKAGE FLOW CALCULATION BY SURFACE STUDY

8.1 Calculation of Leakage flow by considering surface study: [1]

The seat leakage is a combination of laminar and molecular flow. If valve seat leakage is to be considered from initial contact to the molecular diffusion level, all defects like waviness, scratches, roughness, nodules, Localized pits on the surface are to be taken in to account to a relative degree. The height (h) and wave length (λ), can be assumed to represent various waveforms on the surfaces and exist as waviness or roughness or a combination of both.

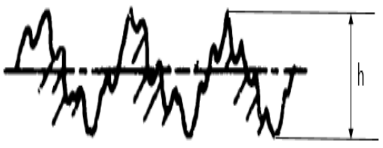


Fig8.1: Surface asperities representation

8.2 Stress calculation based on Surf test:

Stress calculation based on Surftest				
Description	**Symbol**	**units**	**95111MD**	**961111MD**
Wave length of the surface (seal)	λ1	mm	0.25	0.25
Wave length of the surface(metal)	λ2	mm	0.1	0.1
Avg. peak to valley height for Seal surface	h1	mm	0.0017	0.0038
Avg. peak to valley height for metal surface	h2	mm	0.001	0.00085
Avg. asperity slope	φ	rad.	0.0136	0.0304
Elastic modulus for the seal	E1	N/mm2	1400	1400
Elastic modulus for the metal	E2	N/mm2	193000	193000
Outer Diameter	do	mm	12	14.5
Inner Diameter	di	mm	9.3	11.5
Seat Land width	ds	mm	1.35	1.5
Mean seat diameter	D	mm	11.1	13.5
Poissens ratio for the seal	γ1		0.4	0.4
Poissens ratio for the metal	γ2		0.3	0.3
Elastic constant for surfaces in contact	α	1/(N/mm2	0.000595	0.000595
Yield strength	Y	N/mm2	39.3	39.3
Maximum Seat load (Assembled load)	Fm	N	191.87	179.777
Seal land width	W	mm	1.35	1.5
Maximum apparent contact stress	Sm	N/mm2	4.077751	2.827349
Values of the variables			3.676471	1.398026
	A		1.5	0.91
	B		0.4	0.63
	C		1.9	2
Max. apparent stress (to surface yield)	Sm	N/mm2	3.024399	4.249767

Table8.1: Stress calculation based on surface test

8.3 Total Leakage calculation:

STRESS - LEAKAGE		units	**951111MD**	**961111MD**
Inlet pressure	P1	N/mm2	1.6	1.1
Outlet pressure	P2	N/mm2	0	0
Viscosity of the fluid	μ	Nsec/mm2	1.87E-05	1.86E-05
Gravitational acceleration	g	mm/sec2	9810	9810
Stnd.Pressure	P	N/mm2	1.013	1.013
Gas constant	R	J/Kgk	296.8	296.8
Temperature	T	K	313	313
Density	ρ	Kg/m3	17.23705	11.8477
maximum apparent contact stress	Sm	N/mm2	48.84262	9.775289
Apparent seat stress to flatten	Sf	N/mm2	5.871474	13.12447
contact deformation	δ	mm	0.001158	0.001463
Weighted peak to valley height for both surfaces(laminar flow)	HeL	mm	0.000655	0.001669
Weighted peak to valley height for both surfaces(molecular flow)	HeM	mm	0.000588	0.001498
Laminar flow rate	ωL	Kg/sec	4.45E-10	3.83E-09
molecular flow rate	ωM	Kg/sec	4.93E-06	2.41E-05
Leakage due to Laminar flow	QL	mm3/sec	4.09E-09	4.32E-07
Leakage due to molecular flow	QM	mm3/sec	3.37E-05	0.000135
Total Leakage	Q	mm3/sec	3.37E-05	0.000136

Table8.2: Total leakage calculation

From above table of calculations, note that the apparent stress calculated by using surface study is matching with the seating stress that calculated earlier.

Also note that the total leakage is very minute amount which reflects no amount of leakage.

8.4 Experimental tests:

Experimental tests have been carried out for evaluation of safety valve performance by conducting the following tests.

1. Verification of reseat pressure and set pressure with Gaseous nitrogen.

2. Verification of seat leak tightness of PCTFE seal at operating pressure.
3. Verification of seat leak tightness of PCTFE Seal after popup tests with LN2 temperature.
4. Verification of PCTFE Seal performance at ambient and LN2 temperatures with GHe

All the experimental tests that carried along with the Helium Leak Test conducted in Nitrogen storage Facilities using advanced leak test equipment designed by NASA laboratories, the valve with PCTFE sealing performed well and results are very acceptable.

9 CONCLUSIONS

- By knowing the importance of safety relief valve in cryoliquid transportation and storage systems considerable modifications are made, where metal to metal surface contact between the metal disc and nozzle are causing some leakage problem which may result in severe action in limited period of time causing valve burst during usage, may loss valuable piping construction, causes breathing problem due to less oxygen.
- As metal to metal contact surface causing leakage, choosing plastic material which will be able to withstand low temperature and high pressure is best option. Among the plastic kind of materials KEL-F or PCTFE is the best option because of its properties towards low temperatures.
- These modifications considered on the PRV has make proven that these modifications will withstand the conditions that they might undergone by calculating the seating stress acting on the disc in operating condition and proved that it is comparatively can with stand the pressure and seating stress. And by conducting the surface test by considering the surface finish test this study undergone through the micro level where here also proved that KEL-F or PCTFE material can perform well in the operating conditions.
- During the practical testing of the thermal relief valve with the modifications made, **performed till 120 popups** continuously without any minute leakage and still can work. Whereas initially metal to metal contact disc valve fails for every 6 popups that it made.
- So, the modifications in the valve made **increase in performance by 20 times**.

Future Work

With the replacement of metal-metal contact surfaces with metal-soft seal contact surface we got to know that efficiency is increasing. This study won't be stopped at Thermal relief valves, this replacement contributes greater changes in working of various equipment as:

- Replacement of metal contact in Bellow Sealed extended stem cryogenic globe type of valve, which is said to be the costliest valve used in ISRO, lead to drastic savings of money in terms of servicing.
- This can play vital role in Dewars, the storage containers of cryoliquids.

With the study of this project, one can notice that various materials were there to work in cryo conditions, this can be used in studying self-actuating valves as they use diaphragms to work, here these diaphragms fail very frequently so, this kind of study helps in understanding the materials used in cryosystems.

REFERENCES

[1] Rocket Engine Valve Poppet and Seat Design Data Technical Report by NASA

[2] Minimizing pressure relief valve seat leakage through optimization of design parameters By Greig Ritchie

[3] Roark's Formula for Stress and Strain by Warren C. Young, Richard G. Budyna

[4] NEOFLON PCTFE Molding Powder product information by Daikin

[5] Pentair Pressure Relief Valve Engineering Handbook

[6] Polymer data handbook.

[7] Valve selection hand book.

[8] Cryogenic Material Properties Database Cryogenic Material Properties Database -E.D. Marquardt, J.P. Le, and Ray Radebaugh.

[9] The Art of Cryogenics Low-Temperature Experimental Techniques -Guglielmo Ventura and Lara Risegari

[10] Safety Manual for Liquid Nitrogen -S K Kanungo, ISRO Safety Office.

[11] Dynamic behavior of direct spring-loaded pressure relief valves in gas service: Model development, measurements and instability mechanisms C.J. Hos, A.R. Champneys, K. Paul, M. McNeely.

[12] Effect of spring on Operating Characteristic of Spring Loaded Safety Valves Ryousuke Ohta, Katsuhiko Hojoh.

[13] A Numerical Model About The Dynamic Behavior Of A Pressure Relief Valve A. J. Ortega, B. N. Azevedo, L. F. G. Pires, A. O. Nieckele, L. F. A. Azevedo.