CFD MODELING AND ANALYSIS OF RADIAL DYNAMIC SEAL FOR CRYOGENIC SYSTEM

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Abstract— **There are two basic types of dynamic aerospace seals. Face seal and Diametral seal. Face seals are most commonly used in rotating shaft applications. Diametral seals are used in fluid control components (valves) for regulating or isolating propellants in rocket flight stages. Radial seals or diametral seals are used in cryogenic valves for sealing low temperature fluids like Liquid hydrogen, Liquid oxygen and Liquid nitrogen. The basic consideration in dynamic seal joint design is the allowable leak rate and the required operating life of the joint. For cryogenic application the problem become more complex due to more stringent leakage specification and behavior of material at extreme thermal environment. Leakage rate and life of the joint is also a function of surface finish of mating surface, rubbing speed, lubrication, temperature, pressure, deflection etc. Therefore CFD analysis using fluent is done for radial dynamic seals to study the leak flow rate analysis through a micro allowance at varying temperatures, pressures .**

Keywords: ***CFD, cryogenic fluids, frictional coefficient, Knudsen number, Radial seals.***

I. INTRODUCTION

The flow of cryogenic fluids in modern rocket engines is regulated by various valves operating under very severe conditions of pressure, sliding speed and temperature conditions. Radial seals are used in cryogenic reciprocating valves for sealing low temperature fluids for controlling leakage rate and operating life of the joint. The general philosophy of this work has been detected by the requirement to be close as possible to reduce the leakage rate. For cryogenic propulsion systems this fluid control components require special attention in terms of leakage and material behavior at low temperature. Stringent leak tightness is required because of two reasons. First is the loss of working fluid and second is the potential danger of safety, as hydrogen leakage can lead to explosion. Adequate leak tightness can be provided by proper sealing. Most of the materials will become brittle at cryo temperature. Therefore soft sealing materials like rubber and elastomers can't be used. Seal materials like Kel-F and Polycarbonate which can retain its ductility at low temperature can be used for sealing.

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Aerospace fluid control components use various types of seals both Static as well as Dynamic. Presently used aerospace dynamic seals are metallic bellows and lip seals. They occupies large envelope and have more fabricated parts. Bellows required end welding for sealing purpose and lip seals in some cases develop leaks. To overcome this disadvantage an alternate radially loaded (by garter spring) seals can be used as dynamic seal. Here computational study and analytical study is required to understand the seal characteristics. In the present problem sealing mechanism constitutes three elements seal, tube and garter spring. The seal used is a positive contact type dynamic seal. The seal is rubbing against a tubular section made of metallic materials like Inconel 718, SSMDN59 ETC. The clearance between these surfaces creates the leakage which has to be analyzed.

II LITERATURE REVIEW

Most of the researchers around the globe have conducted numerical studies on radial dynamic seals. J K Hetrick and C G Linn, (1966), conducted a study on valve lip seals on M-1 sleeve –type thrust chamber valve. They had given initial seal design configuration based on certain basic stress concentration in combination with applicable datas. Several hundred leakage test with 20 different seal configuration were conducted on thrust chamber valve and valve seal tester and obtain a general lipseal design. W Hubber et al., (1998), carried a experimental study for finding the tribological behavior of material at cryogenic temperatures.

Jean-Luc-Bozet, (2001), done tribological modeling of friction and wear for designing seals in cryogenic valves. It has been illustrated the friction and wear characteristics of polymers rubbing against metals in cryofluids. Also experiments have been performed with various cryofluids to check the rigidity modulus of seal material. Fangui shi and Richard F Salant, (2001), done a numerical study of a rotary lip seal with quasi random sealing surface. They predicted various seal operating characteristics like friction coefficient, reverse pumping rate, film thickness distribion and contact pressure distribution using a mixed elastohydrodynamic analysis.

Roberts R J, (2008), evaluated the Rockwell hardness of plastics, polymers and electrical insulating materials based on D785 standard and determined indentation hardness, rockwell alpha hardness and rockwell hardness number.

III. OBJECTIVES AND SCOPE

The primary objective of this work is to study leak flow through micro gaps using CFD, with varying parameters like gap or clearance, temperature, pressure and fluids. This can be achieved using CFD modeling and analysis of radial dynamic seal using commercial software ANSYS-GAMBIT, FLUENT. More number of valves are present in a cryogenic rocket assembly, the stringent leakages through clearances has to be analyzed. Design optimization of seals is therefore necessary. The future scope of the thesis work lay on the reciprocating valves, where leakage rate is more appreciable.

IV MODELLING AND ANALYSIS

A. Methodology

The test is conducted to determine the leakage rate across the radial seal at varying inlet pressures. In the laboratory the experiment is conducted using nitrogen gas on account of Knudsen number. Figure a shows that the test rig. Initially the entire system is at atmospheric condition. So as to bring down the temperature, Liquid nitrogen is passed through the inlet. Gaseous nitrogen will be coming through the outlet until the system is cooled down to cryo temperature. Supply and outlet is closed when LN2 comes in the outlet. Now gaseous nitrogen at varying pressures, say 10 bar, 20 bar, 30 bar are passed through the system, provided pressure is static. Since, because of the presence of micro gap in between piston and seal, some leak may occur. This is taken out through the leak test part. This leakage can be specified in terms of mass flow rate. In this case, from the continuity equation it can't be determined, since the only known parameters are pressure at inlet and outlet. So CFD can be used to determine the leakage rate

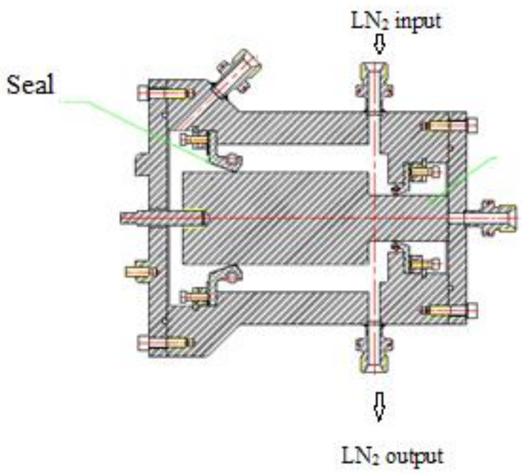

Fig a. Test rig for seal

Actual geometry is simplified and restricted to the region governing leakage. The micro clearance in between the outer surface of the piston and the inner surface of radial dynamic seal will define the mass escaping through the system, termed as leakage. The flown domain can be modeled as shown in figure b. The model is symmetric, the analysis is done only on the half portion of the full 3D geometry keeping the cut plane as the symmetry boundary condition. At the inlet, the Pressure inlet condition is imposed. Pressure inlet conditions vary from 10 bar to 30 bar. Accordingly the gaseous nitrogen temperature is varying from 125 K to 135 K. Walls are taken as adiabatic. The structured mesh of the flow domain is shown in figure 3. CFD analysis is performed on this mesh to obtain the mass flow rate across the gap.

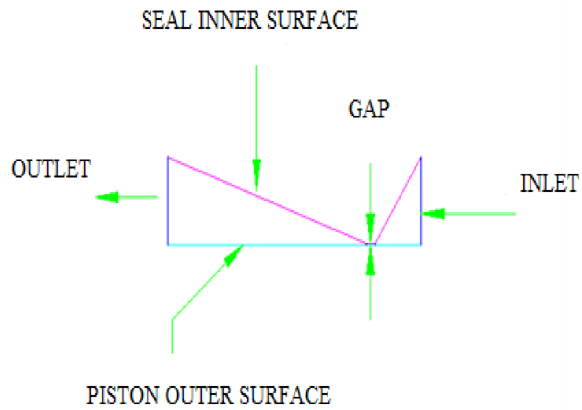

Fig. b Analysis domain with boundary conditions

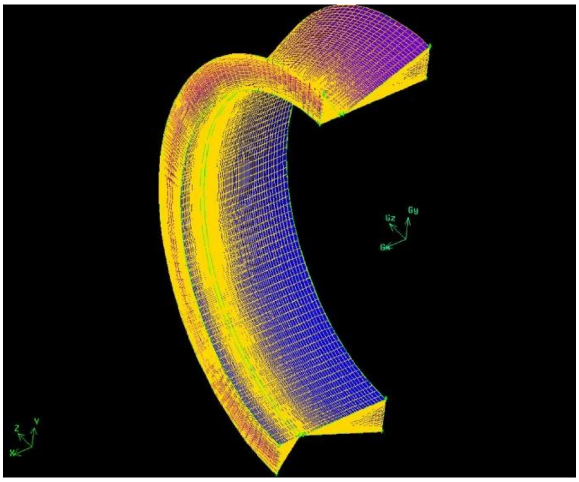

Fig. c Structured mesh of flow domain

V RESULT AND DISCUSSIONS

The steady state analysis is done for radial dynamic seal using gaseous nitrogen as a fluid. Analysis is done with

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varying micro clearance, pressure and cryogenic temperature. The exit condition is same for all the cases. The inlet is shown by the red region in figure d. The outlet condition is atmospheric and shown by blue colour. Throughout the domain pressure is varying. Similarly in figure e it is shown that, the inner surface is experiencing high temperature.

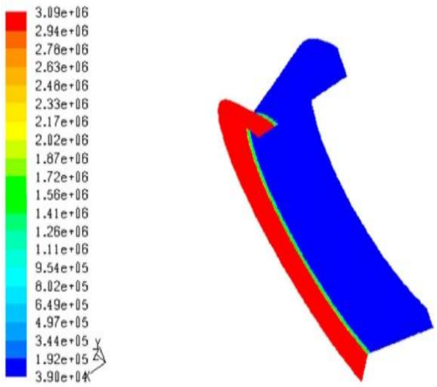

Fig. d Pressure Contour

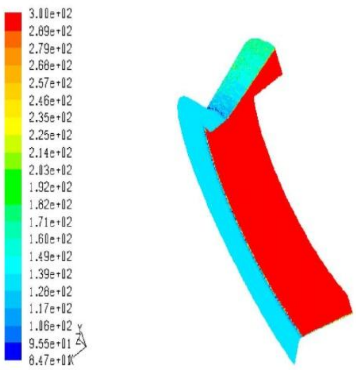

Fig. e Temperature contour

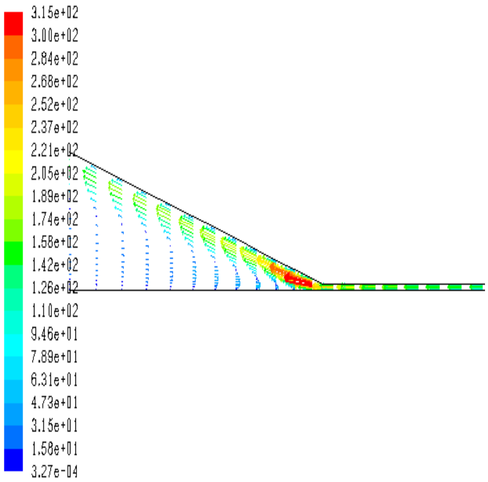

Fig. f Velocity Vector at 10 Bar, Gap 10 ^m

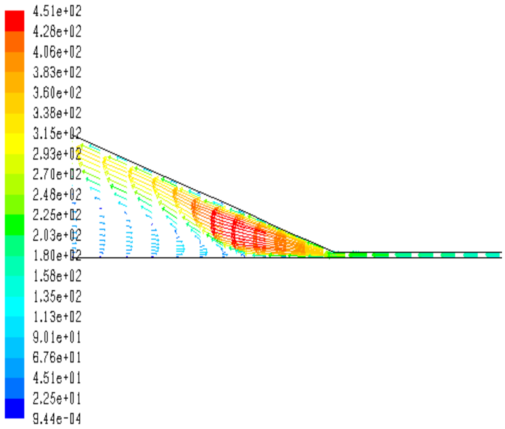

Fig. g Velocity vector at 30 Bar, Gap 10 μm

The effect of back flow of air is shown in figure f and figure g for varying pressures of 10, 30 bar respectively. The back flow of air is less at high pressure and higher at lower temperature. In this case the velocity of mass coming out is influenced by the back flow. Under a gap of 10microns, the analysis results using nitrogen gas are tabulated below table 1.

Table 1: Mass flow rates through 10 micron gap

Temperature K	Pressure bar	Mass flow rate, gm/s
125	10	1.147
130	10	1.119
135	10	1.094
125	20	2.484
130	20	2.428
135	20	2.375
125	30	3.954
130	30	3.90
135	30	3.785

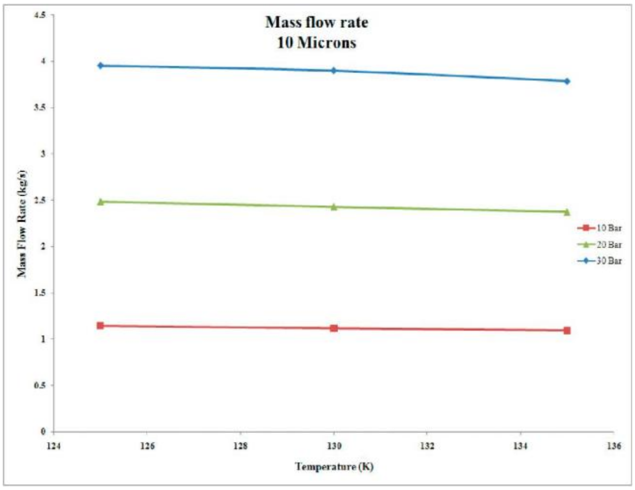

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Fig.h. Mass flow rate variation at different Pressure(10 µm)

From figure 19, it can be observed that the mass flow rate varies for different temperature simulations for same pressure conditions. It can be observed that if temperature lowers the leakage rate increases for the same pressure condition. This is evident from the formula for mass flow rate in one dimensional state given by

m= (Cd Amin PZ) / (√R T1)

Where,

$$Z = \left[g\gamma(2 \,|\, \gamma+1)^{\frac{\gamma+1}{\gamma-1}} \right]^{\frac{1}{2}}$$

VI. CONCLUSION

Mass flow rate through micro clearances is achieved at varying pressures and temperatures using nitrogen gas. Leakage test with gas is done. Experimental analysis for determining leakage test can be done with any gases. If liquids are used, through the micro clearance, large molecules cannot escape easily due to surface tension phenomena. This is the reason why nitrogen gas is taken for analysis in CFD. It is observed that leakage rate is increasing with reduction in temperature. Also at lower pressure the recirculation zones are created which diminishes with increase in pressure. All possible data regarding seal material and leakage behavior is collected and analyzed.

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