Numerical investigation on transient sealing performance of square labyrinth seal in a liquid hydrogen piston pump

Ren H. Y.[1,2], Yang S. Q.[1], Wu W.[1,2], Xie X. J.[1,*]

[1] Key Laboratory of Cryogenic Science and Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences；

[2] University of Chinese Academy of Sciences

* E-mail address: xiexiujuan@mail.ipc.ac.cn (Xiujuan Xie)

Contents

1. Introduction

As a clean energy source, the future of hydrogen energy appears promising!

Numerous developments made in civilian hydrogen transports:

Hydrogen Powered Car

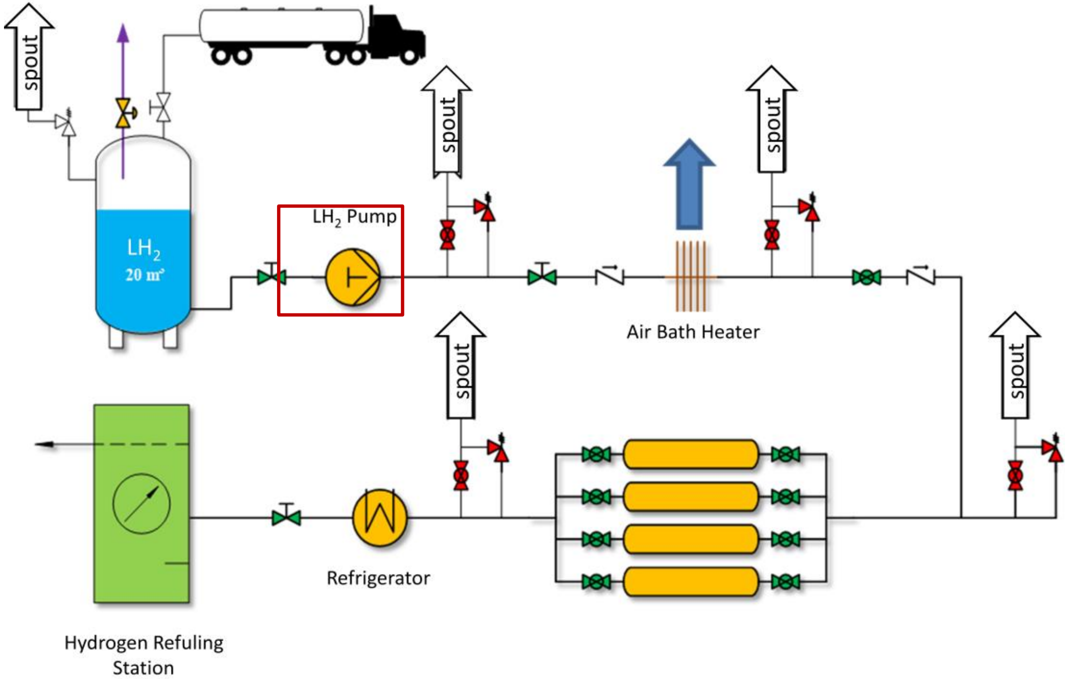
Hydrogen Powered Bus

Hydrogen Powered plane

The potential application for hydrogen energy is substantial!

1. Introduction

Liquid hydrogen refueling station represents an efficient and cost-effective solution for the storage and refueling of hydrogen fuel.



Liquid hydrogen piston pump:

- Core component of liquid hydrogen refueling station
- Liquid compression and lower cost
- Higher energy efficiency

1. Introduction

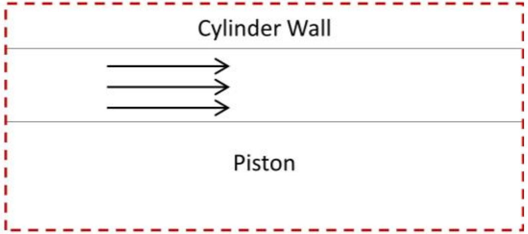
Effective Piston Sealing ⇒ **High Efficiency of LH_2 piston Pumps**

Clearance seal

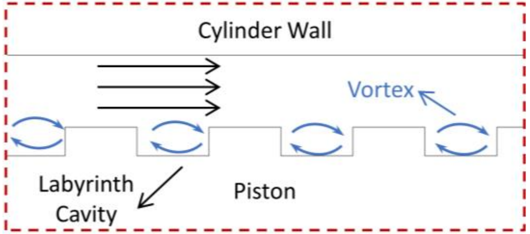
- Non-contact seal;
- Reduce the frictional resistance;
- Reduce the generation of frictional heat.

Labyrinth seal

- A special form of clearance seal;
- To reduce the leakage rate by the throttle effect in teeth clearances and the vortex dissipation effect in cavities.



Clearance Seal



Labyrinth Seal

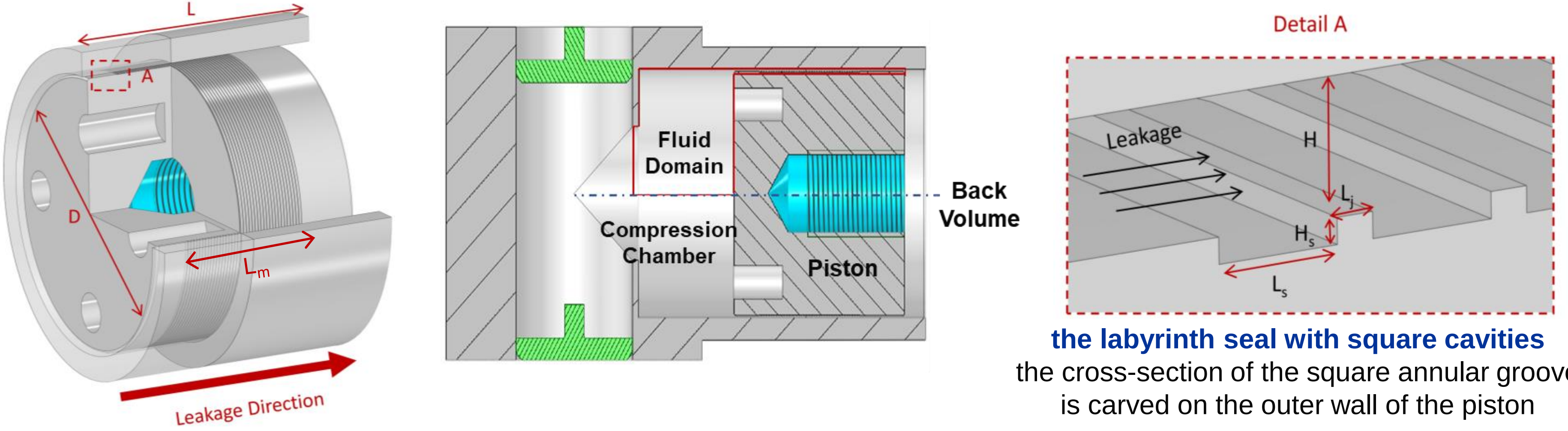
- ☐ A **two-dimensional transient labyrinth seal model** of a liquid hydrogen piston pump
- ☐ The effects of **piston motion, compression chamber pressure and labyrinth seal geometries** on the leakage rate

Contents

1. Introduction
2. Geometry Structure and Its Main Parameter
3. Simulated Results and Discussions
4. Conclusions

2. Geometry Structure and Its Main Parameter

- The pump chamber is divided into a compression chamber and a back pressure chamber by the piston.
- The piston is driven by the piston rod to perform a reciprocating motion within the pump chamber.
- The pressure differential between two chambers leads to the leakage through the labyrinth or clearance seal.



the labyrinth seal with square cavities
the cross-section of the square annular groove is carved on the outer wall of the piston

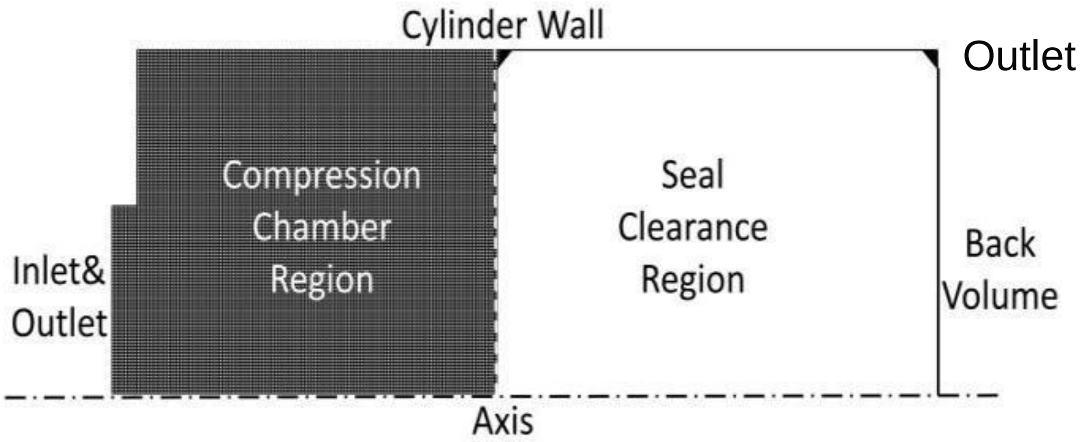
(a) (b) (c)

D: piston diameter, **L**: length of the piston, **H**: clearance height, **L_s**: square cavity length, **H_s**: square cavity depth, **L_j**: cavity interval, **L_m**: labyrinth section length.

Figure 1: Structure schematic diagram of the liquid hydrogen piston pump

2. Geometry Structure and Its Main Parameter

- A **two-dimensional axisymmetric transient clearance seal model**
- The fluid domain is divided into two distinct regions: **Compression chamber region & Seal clearance region,** which are discretized into **a quadrilateral structural mesh**
- The interface between the two regions: an internal surface, thereby establishing a connection between the two fluid regions



- The fluid : a dynamic mesh using the layering method
- The sealing clearance: rigid body motion
- The wall: as a non-slip &adiabatic wall

Figure 2: Fluid domain mesh and boundary conditions

2. Geometry Structure and Its Main Parameter

Independence validation of mesh number:

Seal structure parameters:

- The length of the compression chamber is set to 82 mm.
- D = 110 mm, L = 88 mm , H = 50 μm,
- L_s = 1.0 mm, H_s = 0.2 mm, L_j = 0.3 mm, and L_m = 60 mm.

Pressure boundry conditions:

- The outlet pressure of the discharge stroke: 0.6 MPa,
- The inlet pressure of the suction stroke: 0.3 MPa.
- The back volume pressure: 0 MPa.

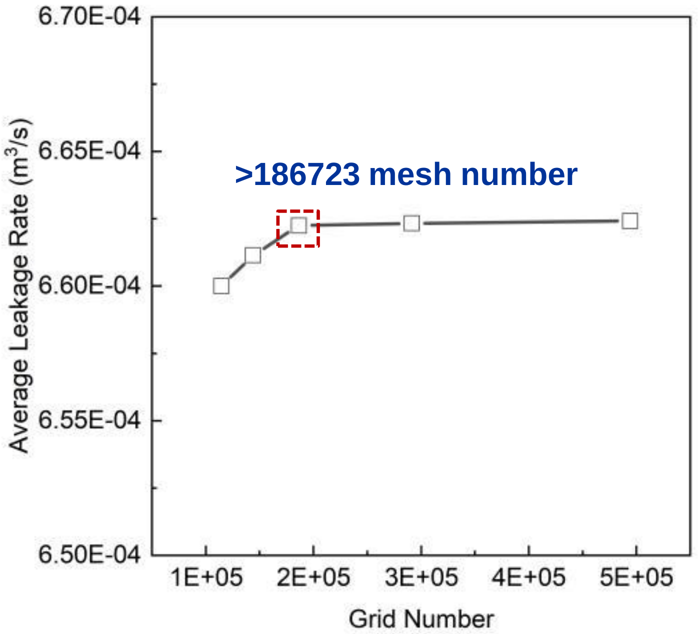


Figure 3. average leakage rate of different grid numbers under the entire cycle

- The 186723 mesh number is chosen for the subsequent calculations after the **Independence validation of mesh number**

Contents

The leakage rate of the clearance and labyrinth seal during the entire cycle

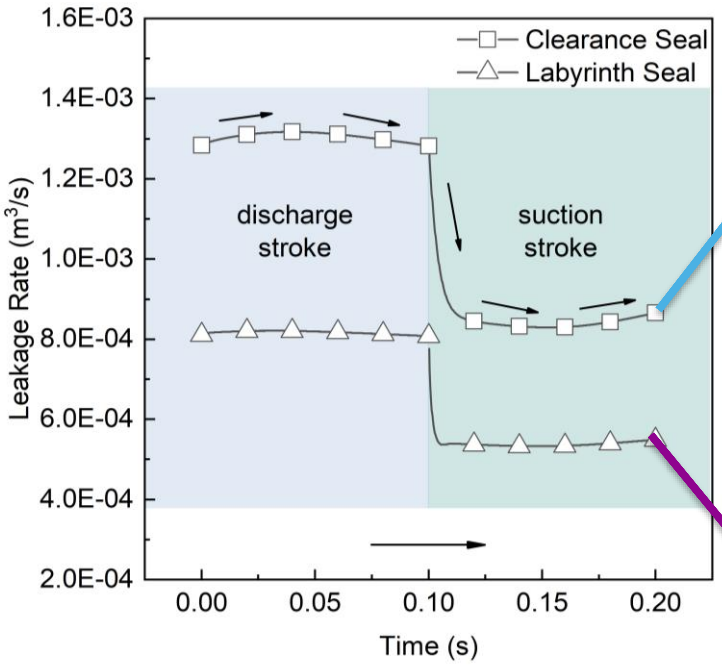


Figure 4.

Clearance seal

- During the **discharge stroke**: the leakage rate
- During the **suction stroke**: the leakage rate

due to the piston's inward extrusion

Labyrinth seal

- To simultaneously reduce the leakage rate and the fluctuations, thereby attenuate the impact of piston motion in comparison to the clearance seal

3. Simulated Results and Discussions

The leakage rate under different discharge stroke pressures in the entire cycle

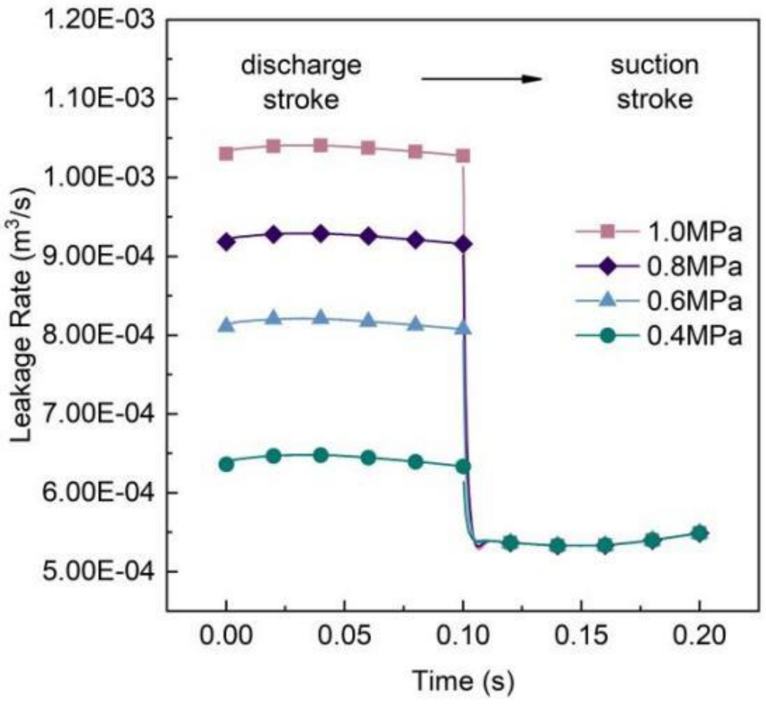


Figure 5

discharge stroke pressures

↓

pressure differential between the compression chamber and the back pressure chamber

↓

the leakage rate

- the leakage rate exhibits an initial increase and a subsequent reduction during the discharge stroke

The Effect of labyrinth section length (L_m) on Average Leakage Rate

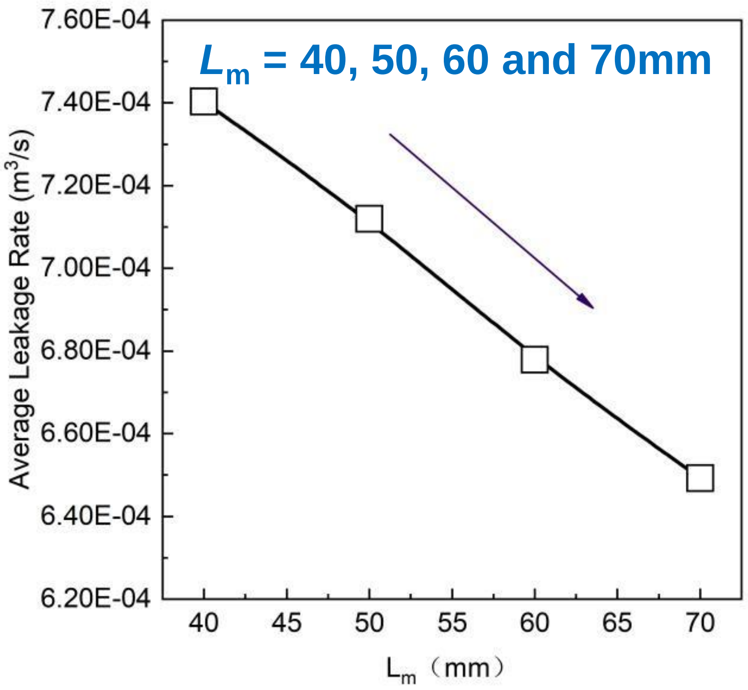


Figure 6

- The longer L_m, the lower the average leakage rate.
- As L_m increases, the number of square labyrinth cavities also rises, accompanied by an increase in flow resistance, intensified kinetic energy dissipation and a reduction in leakage rate.

3. Simulated Results and Discussions

Average leakage rate at various square cavity depth H_s in different square cavity length L_s

- The average leakage rate corresponding to different H_s is calculated for L_s at 0.5 mm, 0.7 mm, 1.0 mm, 1.2 mm, and 1.5 mm, respectively.
- The average leakage rate reduces with L_s.
- In the same L_s, with the increase of H_s, the average leakage rate initially decreases and then increases.
- When length-to-height ratio (L_s/H_s) is approximately 5.0, the sealing effect is the most effective.

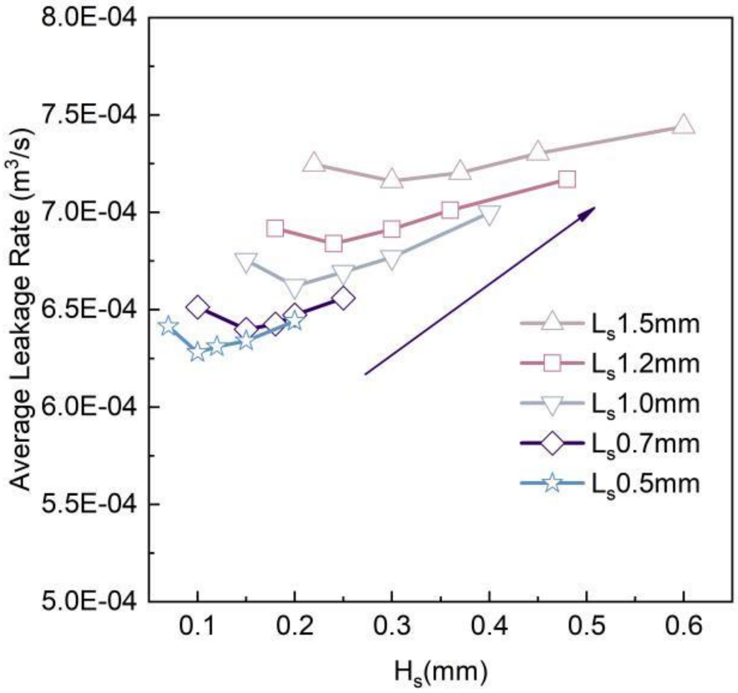


Figure 7

Contents

4. Conclusions

1) The reciprocating motion of the piston results in fluctuations in sealing effect, which are synchronized with the change in piston speed over time.

2) The square cavity labyrinth seal significantly reduces average leakage rate in comparison to a clearance seal, and mitigates the impact of reciprocating piston movement.

3) As the compression chamber pressure increases, the average leakage rate will increase in magnitude. The trend of the leakage rate maintains consistent.

4) Average leakage rate decreases with an increase of the labyrinth section length. There is an optimum square cavity length-to-height ratio of 5.0 to minimize the average leakage rate.

Thank you for your attention !

Email: xiexiujuan@mail.ipc.ac.cn