A Dynamic Optical Measurement System for Cryogenic Fluids Using Laser Interferometry

ZHANG Jinhui  BAO Shiran
ZHANG Ruiping  QIU Limin

Institute of Refrigeration and Cryogenics, Zhejiang University, P. R. China
Introduction

Question: How to observe the fluid behavior?

<table>
<thead>
<tr>
<th>Concentration measurement method</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance method</td>
<td>Simple installation, real-time monitoring</td>
<td>Can’t provide two-dimensional concentration distribution</td>
<td>$\sim 10^{-4}$</td>
</tr>
</tbody>
</table>
Introduction

**Laser interferometry** when coherent lights meet

- Principle: fluid $\rightarrow$ refractive index $\rightarrow$ optical path difference $\rightarrow$ interference pattern
- Application: accurate scale measurement, gas/liquid concentration measurement ($T \approx 300K$)
- Advantage: undisturbed, accurate, two-dimensional

**Question:** Why not apply it to the cryogenic fluid?

- **Seal**
- **Heat insulation**
- **Problems**
- **Contradiction**
- **Requirement:** visualization
Experimental setup

System flowchart

LO₂

LN₂

Gas Chromatograph

MFM

Magnetizer

Magnet

Vacuum Pump

Gas Outlet

Liquid Outlet

Electronic Scale

Computer

Keithley
Optical system

- He-Ne Laser
- Beam Expander
- Beam Splitter
- Test Chamber
- Screen
- Mach-Zehnder interferometer
- Michelson interferometer
- 4 x 45°
- equal-height
- n: 1
Cryogenic system

Visual testing chamber

Key details

- Glasses: high transmittance mutual parallel
- Heat insulation vacuum: \(10^{-4}\)
- Shock insulation
Cryogenic system

- Inner window: glass-ceramic seal welding with kovar, oxygen-free copper gasket
- Outer window: PTFE gasket, quartz glass, fluorine rubber O-ring
- Magnetic field: magnetizer (79 permalloy), magnet needle, magnet (NdFeB)
Calculation

**binary mixture refractive index calculation**

\[
\frac{n^2-1}{n^2+2} = x_1 \frac{n_1^2-1}{n_1^2+2} + x_2 \frac{n_2^2-1}{n_2^2+2}
\]  

(1)

\[n = [x_1(n_1^2 - n_2^2) + n_2^2]^\frac{1}{2}
\]  

(2)

**Lorentz–Lorenz formula**

\[n', \ n_1, \ n_2 — refractive index \]

\[x_1, x_2 — volume \ fraction\]

\[
n' = \frac{1}{2} [x_1(n_1^2 - n_2^2) + n_2^2]^{-\frac{1}{2}}(n_1^2 - n_2^2)
\]  

(3)

What’s the corresponding change of an interference fringe?

\[\Delta n \cdot d = \lambda\]

\[\Delta x_1 \cdot n' = \lambda/d\]

\[\Delta x_1 = \frac{2\lambda}{d(n_1^2 - n_2^2)} [x_1(n_1^2 - n_2^2) + n_2^2]^\frac{1}{2}
\]  

(4)

\[n_1 = 1.221 = n_{LO2}, \ \ n_2 = 1.205 = n_{LN2}, \ \ \lambda = 632\text{nm}, \ \ d = 12.7\text{cm}
\]

If \(x_1 = 0.5\), \(\Delta x_1 = 3.1737 \times 10^{-4}\)
Summary

A non-contact dynamic optical measurement system using laser interferometry are brought in to research the cryogenic fluid

- sensitive to subtle changes of cryogenic fluid concentration
- flexible to study the influence of gradient magnetic field on paramagnetic fluids

As there are rarely related researches, we have much more wok to do

- more refractive index data in low temperature are needed
- more experimental data to make a correction of Lorentz-Lorenz formula
THANK YOU!