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In-situ calibration method of orifice flow meter equipped in 600 W helium refrigerator/liquefier with variable temperature supplies

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HIGHLIGHTS

- An in-situ calibration method of a flow meter has been developed.
- A quarter circle orifice with $\beta = 0.38$ was calibrated at high Reynolds numbers.
- The orifice is installed in 600 W helium refrigerator/liquefier.
- A dummy heat load technique succeeded to estimate mass flow rates.
- The obtained coefficients of discharge are consistent with those of previous studies.

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ABSTRACT

A 600 W helium refrigerator/liquefier with variable temperature supplies was constructed in the National Institute for Fusion Science (NIFS). The mass flow rate of supply Supercritical Helium (SHe) is important information for its performance tests and experimental uses. A quarter circle orifice, according to Verein Deutscher Ingenieure and Verband Deutscher Elektrotechniker (VDI/VDE) 2041, is equipped as a mass flow meter. In the case of the configuration of our system, it is recommended to calibrate the orifice under identical operation conditions with regard to Reynolds number and installation. Therefore, a new in-situ calibration method of the orifice is developed. A dummy heat load was attached between SHe supply and return ports, and the resulting SHe enthalpy rise gives us the information for a mass flow rate. The obtained coefficients of discharge are consistent with those of previous studies.

1. Introduction

A 600 W helium refrigerator/liquefier with variable temperature supplies was constructed in the National Institute for Fusion Science (NIFS). Taiyo Nippon Sanso Corporation assembled the system, and the cold box (LR280, Linde Kryotechnik AG) is its core. Several cool-down tests of large superconductors and magnets, such as a conductor of ITER Toroidal Field (TF) coil and one of the coil modules of the Central Solenoid (CS) for JT-60SA, and others, will be performed. The cold box equips two coolant supply ports covering from 4.4 K to 40 K. Designed cooling capacities are ≥ 350 W at 4.55 K with 50 g/s of Supercritical Helium (SHe) and ≥ 1 kW – 1.2 kW of 20 K – 40 K Gaseous Helium (GHe). They were successfully confirmed to meet the design specifications [1].

Measurements of the SHe mass flow rate were essential for the SHe cooling performance tests and will be required for experimental uses. A quarter circle orifice is installed in a DN20 straight pipe with 45*D* upstream and 19*D* downstream lengths as a mass flow meter. The orifice's diameter ratio, β, inside pipe diameter, D, and throat diameter, d, are 0.38, 23.8 mm, and 9 mm, respectively. The orifice is selected to match the configuration of the cold box. According to Verein Deutscher Ingenieure and Verband Deutscher Elektrotechniker (VDI/VDE) 2041, the lengths of the straight pipe section upstream and downstream should be $10D \pm 1D$ and must be $\geq 6D$, respectively. The coefficients of discharge, C, are valid for $40\text{ mm} \leq D \leq 150\text{ mm}$ and $0.2 \leq \beta \leq 0.6$. Then it is recommended

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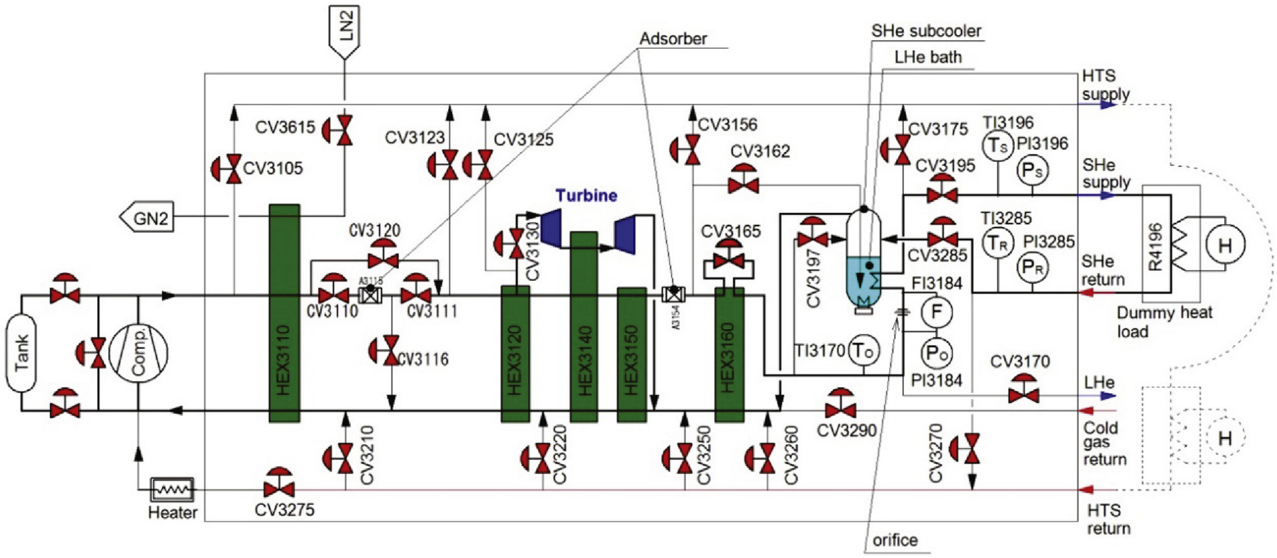

Fig. 1. Flow diagram of the orifice calibration. The 250 W heater, R4196, is installed as a dummy heat load. The LHe level control heater is attached to the LHe bath of the SHe subcooler. A tag number is formed by Input/Output (I/O) information and an assigned number. The I/O information is represented as Temperature Input (TI), Pressure Input (PI), mass Flow Input (FI), Resistance heater (R), and Control Valve (CV). Components: HEX**** and Comp. are heat exchanger and compressor, respectively. Abbreviations: LN_2, GN_2, LHe, and HTS are Liquid Nitrogen, Gaseous Nitrogen, Liquid Helium, and High Temperature Superconductor, respectively. The HTS supply will be used for cooling of HTS tests, which was not applied for this study.

to calibrate orifices in the case of inside diameters of a pipe $D < 40$ mm or throat diameters $d < 15$ mm and, moreover, to perform the calibration under identical operation conditions with regard to Reynolds number and installation.

Several studies were conducted on C of quarter circle orifices [2–4]. Upstream straight lengths are 24D, 90D, and 59D in the measurements of references 2, 3, and 4, respectively. Their downstream lengths are 12.5D, 40D, and 74D, respectively. Focusing on $\beta = 0.4$, their throat diameters are 16 mm, 6.4 mm, and 41 mm, respectively. The previous studies can be summarized as follows. Contrary to VDI/VDE 2041, a small peak around 1000 of Reynolds numbers, Re_D appears on a Re_D versus C curve. In these experimental conditions, the longer the upstream straight length is, the higher the peak becomes. After that, C is constant up to the upper constancy limit. The discrepancies of C values among the previous studies are within a few% in spite of d variations. Then the curve rapidly rises as Re_D increases and reaches the peak. Then the curve rapidly decreases. There are variations between the peak values of references 2 and 4. In terms of our main operation range over the constancy limit, the dependence of C on Re_D is still uncertain.

In order to use the orifice as a mass flow meter, we propose the new in-situ calibration method. An additional dummy heat load makes it possible to calibrate the orifice under the actual operating condition. In this paper, we describe the details of the new in-situ calibration. Then its validity is discussed by comparing obtained C values to those of the previous studies.

2. Experimental and calibration details

A dummy heat load is added for the estimation of mass flow rates. The flow diagram of calibrations is shown in Fig. 1. After HEX3160, SHe flows to the subcooler through the orifice tagged as FI3184 which is installed in a vertical straight pipe. The details and the installation condition of the orifice are shown in Fig. 2. To measure the differential pressure, Δp, corner tappings are applied, and they are connected to pressure sensors at room temperature via pipes with a 4 mm inner diameter. The SHe is cooled at the subcooler and then goes to the SHe supply port. A dummy heat load, which resembles a pipe with vacuum insulation and Super-

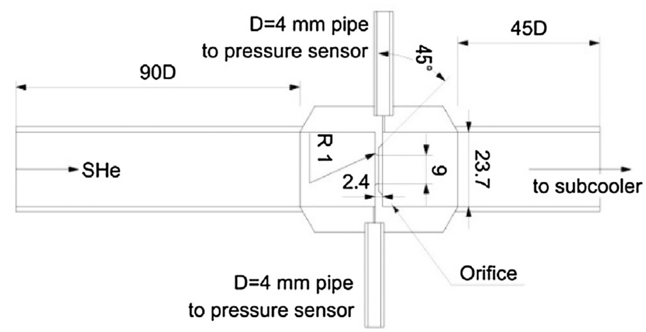

Fig. 2. Installation condition of the orifice in the cold box.

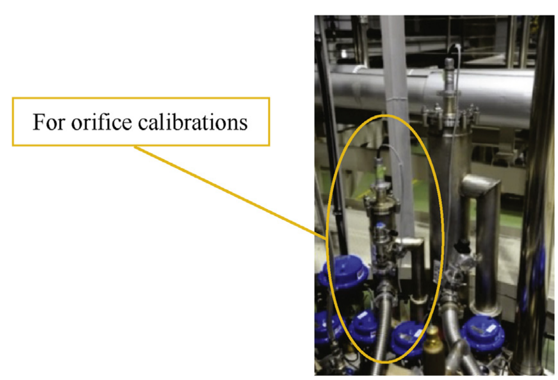

Fig. 3. The left hand side is the dummy heat load to use for calibrations.

Insulation (SI) as shown in Fig. 3, was connected between the SHe supply and return ports. After the dummy heat load, the SHe was flushed to the Liquid Helium (LHe) bath of the subcooler through CV3285 and was partially changed to LHe because of the Joule-Thomson *(JT)* effect.

A mass flow rate is estimated from the enthalpy rise, ΔH, at the dummy heat load as follows. The gross heat load at the dummy heat load is the sum of the heater power, Q_{Heater}, and unknown heat