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Bubble counter based on photoelectric technique for leakage detection of cryogenic valves*

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Abstract: In order to overcome the inconvenience of manual bubble counting, a bubble counter based on photoelectric technique aiming for automatically detecting and measuring minute gas leakage of cryogenic valves is proposed. Experiments have been conducted on a self-built apparatus, testing the performance with different gas inlet strategies (bottom gas-inlet strategy and side gas-inlet strategy) and the influence of gas pipe length (0, 1, 2, 4, 6, 8, 10 m) and leakage rate (around 10, 20, 30, 40 bubbles/min) on first bubble time and bubble rate. A buffer of 110 cm^3 is inserted between leakage source and gas pipe to simulate the downstream cavum adjacent to the valve clack. Based on analyzing the experimental data, experiential parameters have also been summarized to guide leakage detection and measurement for engineering applications. A practical system has already been successfully applied in a cryogenic testing apparatus for cryogenic valves.

Key words: Photoelectric technique, Bubble counter, Leakage detection
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INTRODUCTION

With wider application of cryogenic valves in many fields, such as air separation unit, liquid natural gas industry and space propellant system, many manufacturers devoted or are devoting their efforts to this aspect (Weilert *et al.*, 2001; Veenstra *et al.*, 2007). Since cryogenic valves are operated at low temperatures, their product quality requirements are quite different from those for ordinary valves (British Standards, 1984; Jia *et al.*, 1992). Besides the routine test as ordinary valve, cryogenic test generally becomes a necessity before a cryogenic valve is put into service. Axial gas leakage is one of the key testing items, especially for those cryogenic valves with hard sealing, which have allowable leakage (Zhu, 2000).

Gas leakage also exists in other practical engineering applications, and there is obvious necessity of detecting the leakage qualitatively or quantitatively. Many different methods such as bubble detection, pressure-change detection, halogen detection, chemicals penetration and trace are adopted in the practice (Jenkins, 1952; Mahoney *et al.*, 1997; Genenger and Lohrengel, 1992; Tang *et al.*, 2002; ANSI/ASTM, 2005; Gong *et al.*, 2005). A flowmeter, a bubble counter and a helium mass spectrometer are often used in large, small and tiny leakage cases, respectively. Manual bubble counting methods have such disadvantages as time- and labor-consuming, inconvenience and inaccuracy due to the manual operation. Additionally, for some special cases, for instance, dangerous and toxic gas systems, the bubble counter may not be on the spot, so that the leaked gas needs to be transferred to the counter at a certain distance.

Thus, an automatic detection and measurement (D&M) scheme with photoelectric technique, based on the principle that light transparency of a water column varies evidently when a bubble passes through, is introduced (Juds, 1988). A photoelectric

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bubble counting system has been built up and experiments have also been conducted with various parameters, especially gas pipe length and bubble rate, to simulate practical operating conditions. Several experiential parameters are summarized to guide practical applications, based on the analysis of experimental data.

PHOTOELECTRIC BUBBLE COUNTER AND PERFORMANCE TEST

An automatic bubble detection experimental system based on photoelectric technique has been built up. The apparatus is mainly composed of gas source, pressure-reducing valve, leakage adjusting valve, buffer, gas pipe (nylon), glass tube, photoelectric D&M unit, computer-based data acquisition (DAQ) system, and regulated power supply, as shown in Fig.1.

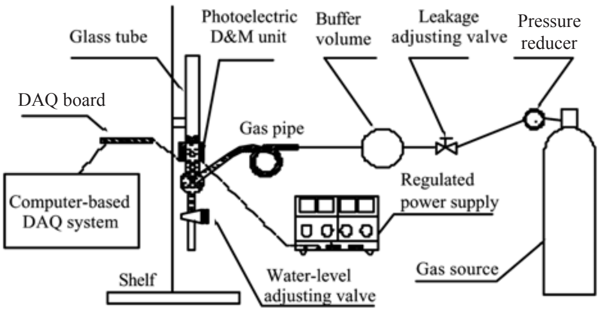

Fig.1 Experimental apparatus of bubble counting system based on photoelectric technique

The glass tube is filled with water column. Two different structures with different gas inlet strategies, as shown in Fig.2 and Fig.3, have been tested. The former (U-shaped) structure has its gas inlet at the bottom of glass tube (namely bottom gas-inlet strategy), while the latter (V-shaped) one has gas inlet at its side (namely side gas-inlet strategy). In Fig.3, the gas obliquely goes downwards into a ball reservoir, which aims at reducing the disturbance of water column.

For some applications with inconvenience or even danger for fieldwork, the leakage should be led out of spot to measure, hence, there exists a distance between D&M unit and gas leakage point. Different lengths of gas pipe (0, 1, 2, 4, 6, 8, 10 m) with a fixed inner diameter of 6 mm were prepared to simulate

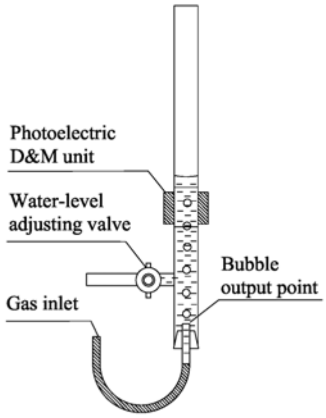

Fig.2 Glass tube with a bottom gas inlet

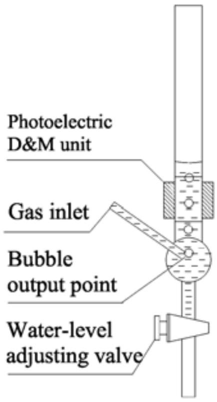

Fig.3 Glass tube with a side gas inlet

those operating conditions in experiments. Besides, cavum frequently appears downstream adjacent to the valve clack. A buffer of 110 cm^3, between leakage adjusting valve and gas pipe, is added to simulate this cavum, since this may affect first bubble time (FBT) and bubble rate (BR). The first bubble time means the time for the first bubble going through the detection window after gas source is connected to the system, and the bubble rate stands for the bubble numbers passing the glass tube per minute.

The photoelectric D&M unit is composed of LED, loophole and silicon photo-cell. The LED is powered by a regulated power supply. The signal from silicon photo-cell is a stable voltage when no bubble goes through the glass tube, while a voltage jump appears when a bubble is passing. The voltage signal is acquired by the computer-based DAQ system, which is composed of NI-PCI 6010 DAQ board and LabVIEW based program. If the jump is larger than a preset threshold, the program automatically counts once and calculates the corresponding leakage rate and accumulative leakage volume. These treated results are demonstrated on the screen and stored in the computer.

In the experiment, the leakage rate is controlled by leakage adjusting valve, while the water level (from the bubble output point) in glass tube is controlled by water-level adjusting valve (a 5-cm-height water level is adopted in the following experiments). Four bubble rates (around 10, 20, 30, 40 bubbles/min with 0 m gas pipe) are tested to simulate different leakage flux in practical applications. The reason to choose these typical bubble rates is the convenience for comparison with manual counting. Rate up to 200 bubbles/min has been tested and the DAQ system can successfully count the voltage impulse due to the bubble passing through the glass tube. To ensure that the tests are conducted under the same leakage conditions, the opening of leakage adjusting valve should be fixed and the valve inlet pressure should be constant by adjusting the pressure reducing valve. The first bubble time together with bubble rate at different lengths of gas pipe and for the cases with or without buffer is measured.

TESTING RESULT AND PRACTICAL APPLICATION

Experiments on the bottom gas-inlet strategy, as in Fig.2, show that the generated bubbles are not stable and uniform, including bubble speed and bubble size, which brings unavoidable measurement error. When gas passes through the bottom of the U-shaped structure, a bubble will not be released immediately but intermittently and irregularly after forming a certain length of gas column to overcome the weight of water column. However, the bubble from the side gas-inlet strategy shown in Fig.3 is more stable and also with uniform size, thus, the side gas-inlet helps to guarantee measurement accuracy. The results discussed in the following context are all from the V-shaped structure with a side gas-inlet.

For generalization, the experimental results of FBT and BR will be normalized in two relative parameters: relative first bubble time (RFBT) and relative bubble rate (RBR), which are expressed as a ratio of the value at variable length of gas pipe to that at 0 m pipe length.

$$RFBT = \frac{FBT_{\text{variable length}}}{FBT_{0\text{ m}}}, \tag{1}$$

$$RBR = \frac{BR_{\text{variable length}}}{BR_{0\text{ m}}}. \tag{2}$$

In the case of no buffer, the RFBT varies rough-linearly with the gas pipe length, as shown in Fig.4a, and increases by about 0.12 per meter as the gas pipe length increases. The relationship between RBR and gas pipe length can be analyzed from Fig.5a, which shows that the RBR decreases by about 0.03 per meter as the gas pipe length increases.

A buffer of 110 cm^3 is installed between leakage adjusting valve and gas pipe to simulate the cavum downstream adjacent to valve clack. The relations of RFBT and RBR versus gas pipe length are shown in Figs.4b and 5b, respectively. The RFBT increases by about 0.08 per meter as the gas pipe length increases, while the RBR decreases by about 0.015 per meter as the gas pipe length increases.

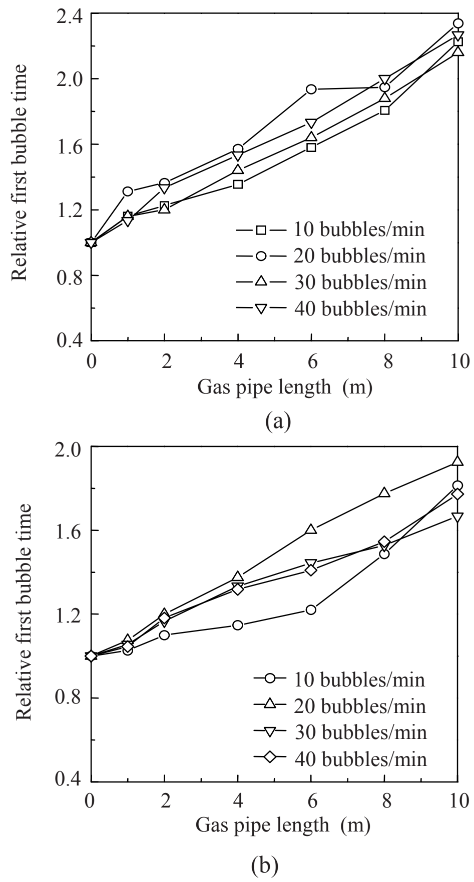

Fig.4 Relative first bubble time vs gas pipe length without (a) and with (b) buffer

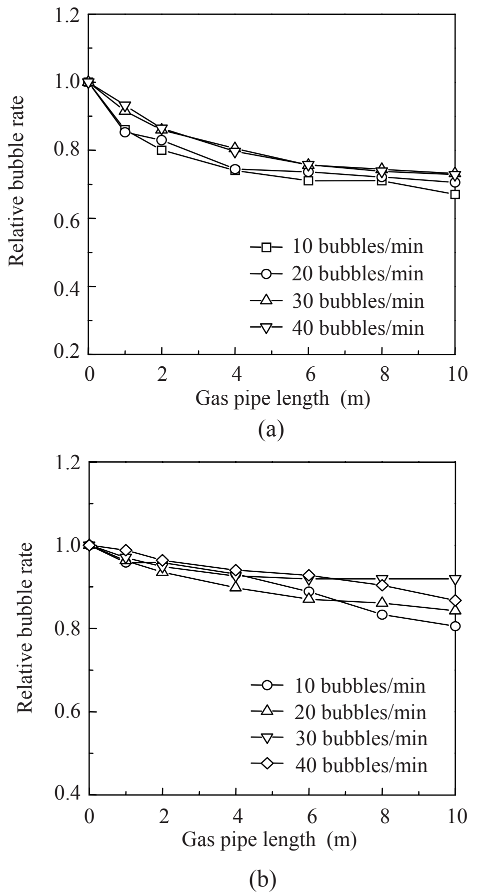

Fig.5 Relative bubble rate vs gas pipe length without (a) and with (b) buffer

Comparing the cases with and without buffer, the curves of RFBT and RBR versus gas pipe length both have approximate linear trends, despite the difference in the slope of the lines. The slopes for the cases with buffer are smaller than those for the cases without buffer.

Based on the above experimental tests, an improved bubble counter has been fabricated for minute leakage measurement of cryogenic valves. The testing system shown in Fig.6 includes gas source, insulated test tank, cryogenic valve to test, selfpressurized cryostat, leakage testing unit, computer-based DAQ system and pipe network (including controlling valves symbolized V1, V2, …, V11). The leakage unit is composed of two parts: flowmeter and bubble counter. The flowmeter adapts to the case of high leakage rate by opening V9 and closing V10, while the bubble counter aims at the minute leakage by opening V10 and closing V9. An unknown leakage from the tested valve, going through V7 and V8, is generally introduced to the flowmeter first. If the DAQ system shows that the leakage is smaller than the lower test limit of flowmeter, the measurement will then be shifted to bubble counter. The minute leakage can be calculated through the multiplication of bubble rate and volume per bubble, which can be measured and summarized beforehand.

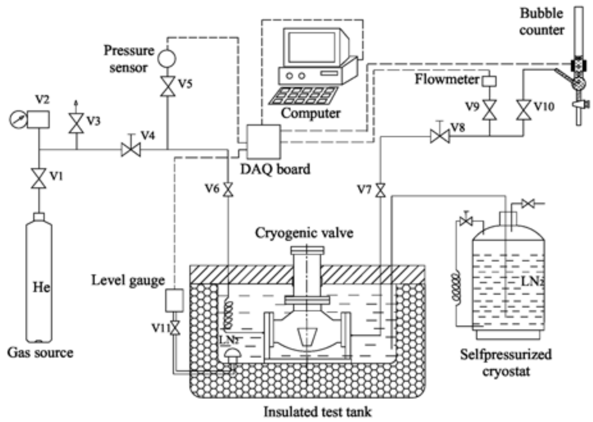

Fig.6 Cryogenic testing system for cryogenic valves including a photoelectric bubble counter

A smooth operation of the whole cryogenic test system in practice verifies the feasibility of the photoelectric bubble counter. A leakage with a bubble rate slower than 200 bubbles/min can be covered by the present photoelectric bubble counter. This bubble rate is generally too fast for manual counting, while the volumetric leakage is too low compared with the measuring limit of a common flowmeter. Therefore, the photoelectric bubble counter has the outstanding advantages within the transitional range between flowmeter and traditional manual bubble counter.

CONCLUSION

In order to overcome the disadvantages of manual bubble counting (inconvenience, inaccuracy and insecurity), a novel automatic bubble counter based on photoelectric technique was proposed and built up. The experimental results demonstrate that our photoelectric D&M bubble counter can run smoothly when the bubble rate is lower than 200 bubbles/min.

Laboratory study on the influence from structural factors led to the following conclusions. RFBT and RBR both vary rough-linearly with gas pipe length. The introduction of a buffer between leakage adjusting valve and gas pipe does not influence the approximate linear relationship, but results in a different slope. For the case without buffer, the RFBT increases about 0.12 and the RBR decreases about 0.03 for gas pipe length increase of 1 m, while, with a buffer inserted, the RFBT increases about 0.08 and the RBR decreases about 0.015.

The photoelectric-technique-based bubble counter has the advantages of compact structure and low cost. A practical system has already been successfully applied in a cryogenic test apparatus for cryogenic valves.

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