Application of PIV technique to cavitating flows of liquid helium

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PIV technique was applied to the measurement of bubbly flow of cavitating liquid helium driven by a bellows pump. In the present PIV application the velocity of cavitation bubbles is measured without adding any seeding particles. The flow field, the downstream of the Venturi throat, is separately illuminated by two stroboscopes through an optical window of the cryostat, and subsequent two successive pictures of cavitaion bubbles are taken by a digital CCD camera. The image information o ! the two pictures is analyzed with the aid of a PIV algorithm to yield a 2-D velocity distribution of cavitation bubbles. It may be concluded that the application of PIV technique is of great use in the quantitative study of cavitaion flows of He I and He II.

INTRODUCTION

Liquid Helium shows some unique physical characteristics, such as lamda phase transition, thermal counter flow, and quite a low dynamic viscosity. Only a few researches based on velocity measurement have been conducted. They are Laser Doppler Velocimetry (LDV) application with seeding particles made from mixture of hydrogen and deuterium [1], and Particle Image Velocimetry (PIV) application with hollow glass spheres [2] or polymer micro-spheres [3] as seeding particles, both of which were applied to the thermal counter flow measurement of He II. Though LDV enables a point measurement, two dimensional axial velocity can be measured with much difficulty. On the other hand, PIV enables essentially a two dimensional measurement. In both researches, some discrepancies have been still pointed out between the measurement results and theoretical ones. One of the reasons for the discrepancy is attributed to low dynamic viscosity. It seems rather hard to select suitable tracer particles in He II that must be as close as neutrally buoyant and capable of flowing with sufficiently small slip with respect to He II flow compared with ordinary fluids like water. Consequently, we first applied the PIV technique to cavitating flow through the Venturi channel without adding tracer particles. In this PIV technique we don't use laser light of which scattered light from tracer particles is used in conventional PIV technique, but, instead, we used bubbly flow patterns illuminated by the back light from two stroboscopes. By doing this, we could avoid the risk arising from the difficulty concerning tracer particle, and examine the validity of the PIV technique for the application in liquid helium flows measurement.

EXPERIMENTAL APPRUTUS

The cavitating flow in the Venturi channel is driven by the bellows pump. In the present PIV application no seeding particles are added because cavitation bubbles play a role of particles [4]. The optical system is composed of four parts, that is the digital CCD camera, the light source, the timing synclonyzer, and the image memory system. The Digital camera, MegaPlus Model ES 1.0 (REDLAKE MASD Inc.) is capable of taking successive two pictures with an interval at the least 1 " s at the maximum repetition frequency of 12 Hz. The image resolution is 1008x1018 pixels. In this experiment, we took two pictures with 10 _s-interval at 10 Hz. The light source, a fiber video flash Model FB-05J30 (Nissin electronic Co. Ltd.) is composed of two independent channels and the output power is 0.5 J/flash with a half value width of 3 _s. The setting of the light source is easy due to independent two units of fiber light guides. The timing synclonyzer and the image memory system are controlled by a personal computer. A number of sets of pictures are temporarily accumulated on an interface board, and then are stored in a hard-disk memory.

PIV BASIC THEORY AND APPLICATION

For the application of the PIV technique, synchronized timing for each device is quite important. The timing chart is shown in Fig.1. The timing of two pictures is decided according to the formula as

$$U_{throat} = \frac{L}{k}\frac{\ddot{A}X}{\ddot{A}t}, \tag{1}$$

where U_{throat} is the throat velocity of liquid helium, L the characteristic length of the field of view, _X the displacement of an image measured in pixels between two successive pictures, k the pixel resolution of a camera, _t the time interval between two pictures. Here, _X is decided depending on the particular method of PIV analysis. We adopted the cross-correlation method software developed by Sakakibara Laboratory of University of Tsukuba, in which appropriate _X is recommended to be about 10 pixels. The two pictures are taken at the instances of the stroboscope emissions.
In this experiment, we have U_{throat} about 20 m/s, L about 10 mm, k about 1000 pixels, and _X about 10 pixels, and consequently _t is about 5 _s. We select the value of _t to be 10 _s because we estimate that the actual #t becomes larger due to a little slow down of the flow velocity in the high bubble area compared with the throat velocity.

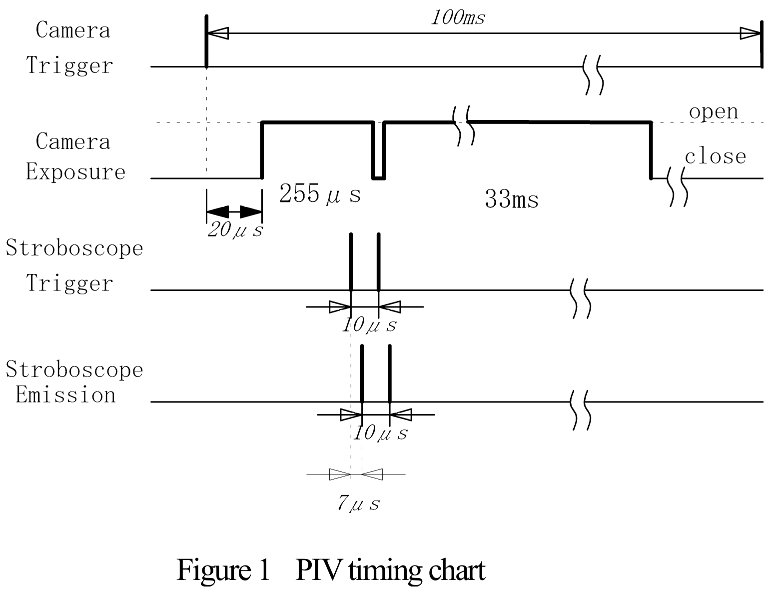

Figure 1 PIV timing chart

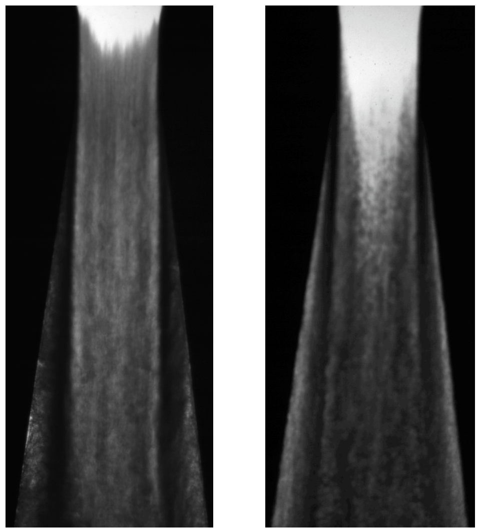

Figure 2 Whole cavitating flow area of He I (left, temperature=2.5 K), and He II (right, temperature=2.1 K), both U_{throat}=21.5 m/s

RESULTS AND DISCUSSION

The still pictures of the cavitating flows of He I and II in the Venturi channel are respectively shown in Fig. 2. The PIV analysis area is the middle square region of the downstream of the Venturi channel, 11 mm below the throat with a size of 10 mm x 10 mm.

He I cavitating flow

The picture of a typical He I cavitating flow and its PIV analysis result that is an ensemble average of 6 data are shown in Fig. 3. It is seen that the PIV result has a good enough spatial resolution to distinguish the thin shear layers indicating the boundary between the central and the separated layers on both sides of the flow-field. In both separated flow regions, reverse flows can be recognized. This can be also seen from the velocity distribution shown in Fig. 5 which is drawn on the basis of the PIV result. The PIV result indicates the average velocity of cavitating flow in the potential core region is about 16.1 m/s.

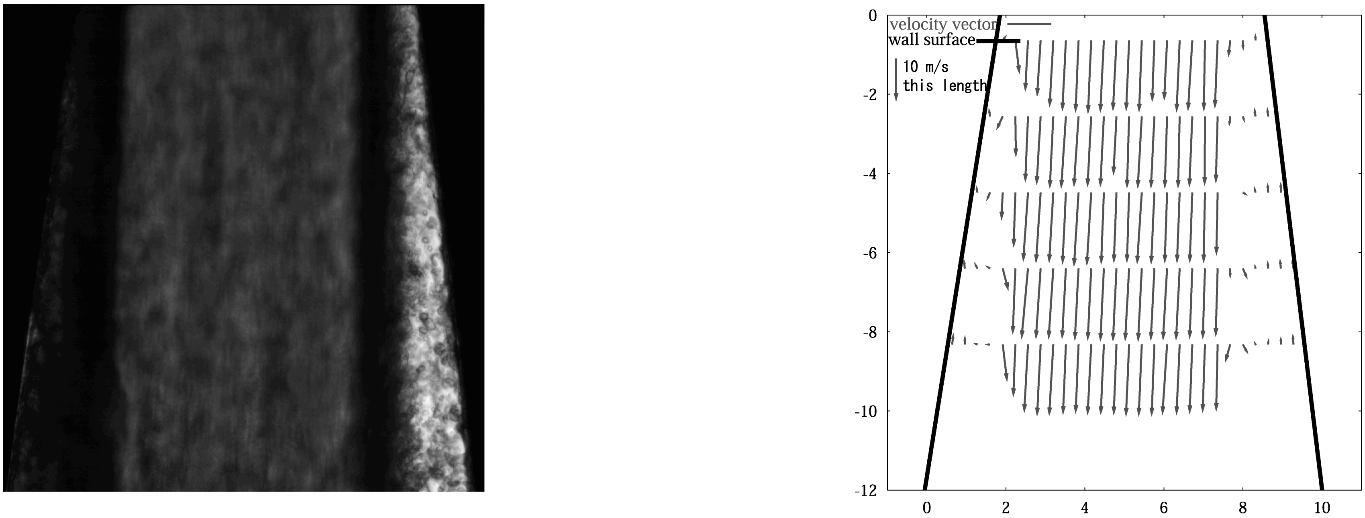

Figure 3 Typical He I cavitating flow picture and the PIV result shown in a velocity vector form (ensemble average of 6 data), T=2.5 K, U_{throat}=21.5 m/s

He II cavitating flow

The similar result for He II flow is presented in Fig. 4. Clear difference from He I cavitating flow is seen with respect to less clear shear layer and apparently no reverse flow in the separated flow region. The latter result of no reverse flow is also seen in Fig. 5. The trough in the middle of the potential core region is an erroneous result presumably caused by lack of bubbles there. The average velocity of cavitating flow in the potential core region is about 15.8 m/s.

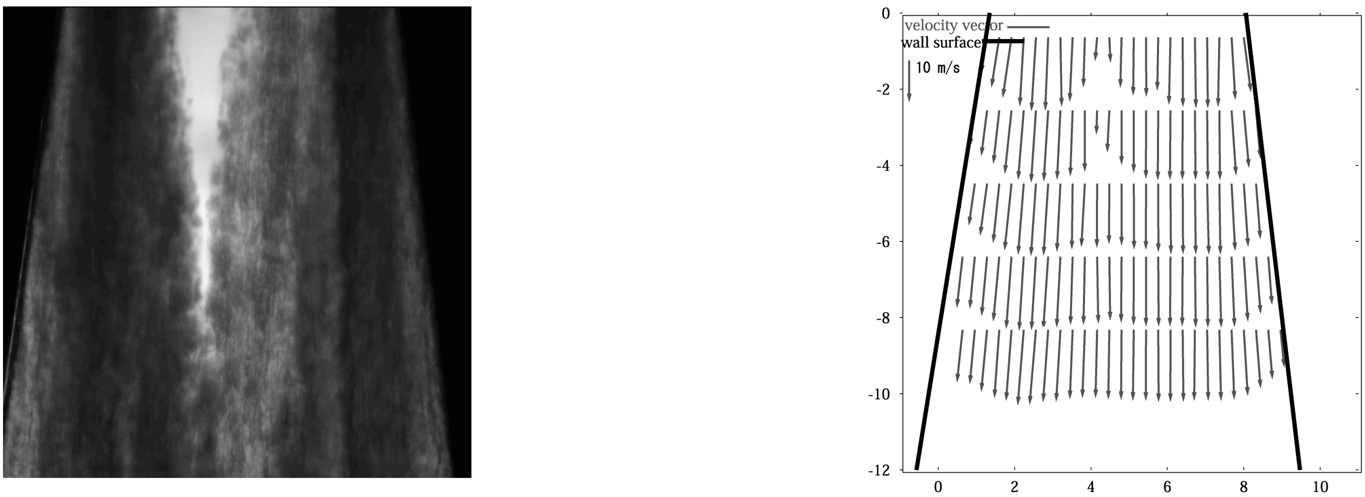

Figure 4 Typical He II cavitating flow picture and the PIV result shown in a velocity vector form (ensemble average of 6 data), T=2.1 K, U_{throat}=21.5 m/s.

Discussion

It may be concluded that the present PIV application yielded rigorous result as presented in Figs. 3 and 4. In fact, the average correlation coefficient in the procedure determining the spatial displacement of an image to calculate the flow velocity was all larger than 0.7 and a single strongest peak value could uniquely resulted in every interrogation region throughout the flow field. And apparent error vectors were not found in both Figs.3 and 4. Figure 6 shows relationship between a measurement area and a number of interrogation regions. A velocity vector in each interrogation regions is calculated from the average bubble movement during the interval Δt for two successive pictures, that is decided by the maximum correlation principle. In the present PIV analysis, an interrogation region of 64 x 64 pixels (one pixel is about 10 μm) is used with an overlap of 50% of each interrogation region. The spatial and time resolutions may be around 320 μm and about 0.1 sec, respectively.

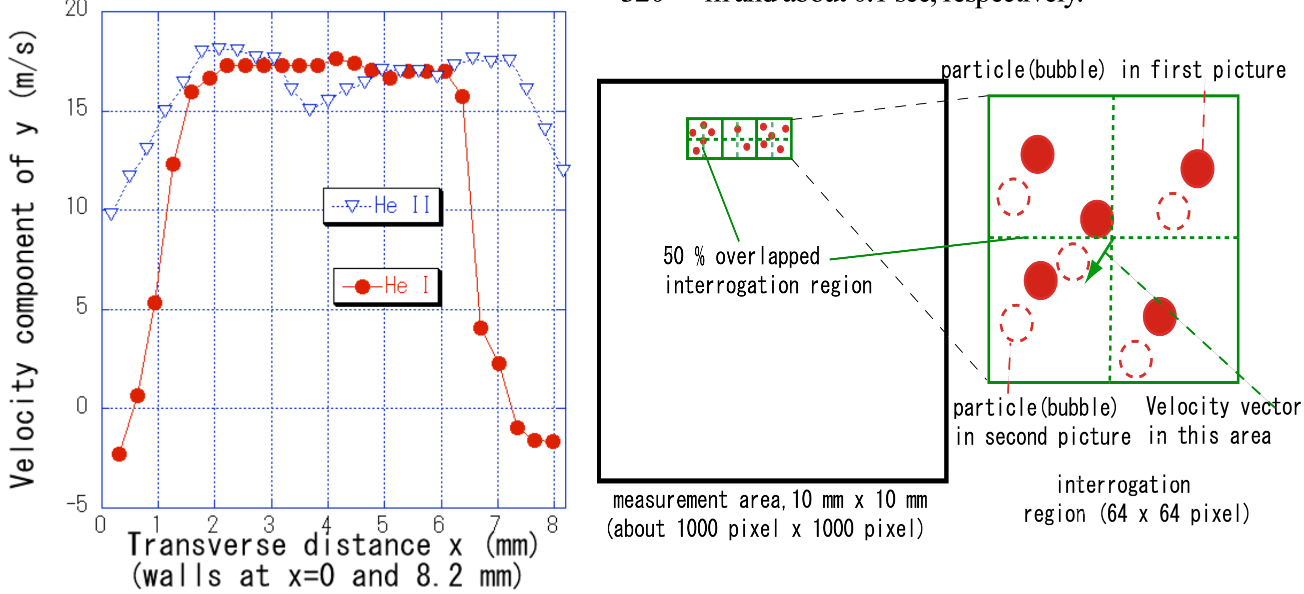

Figure 6 PIV image analysis

CONCLUSIONS

1. PIV technique can be successfully applied to cavitating flows of liquid helium, both He I and He II.
2. Using PIV technique, we can measure the bubble velocity with a 320 μm spatial resolution and 0.1 s time resolution.
3. Difference between He I and He II cavitating flows can also be clearly indicated by the PIV result.

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