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THE MEASUREMENT OF VELOCITY DISTRIBUTION OF LIQUID BRIDGE AT OSCILLATORY STATE BY PIV METHOD

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1. Introduction

The Thermocapillary convection is a typical subject in microgravity science, since it has significantly affected many applications in science and technology. Many works, have been performed on thermocapillary flow in half floating zone configurations due to easiness of simulating microgravity since 70's [1—2]. Most studies analyze the transition from steady convection into oscillatory convection. The critical state has been determined experimentally by temperature measurement of inserting thermocouple inside the liquid bridge or near the free surface of liquid bridge [3—4].

Recently the thermocapillary convection in half floating zone has been studied in more detail, and some nondestructive methods of optical diagnostics were developed to measure the oscillallatory features of liquid bridge. such as, a micro-video system was designed to measure the variation of boundary edge of the liquid bridge[5]. Furthermore, the deformation of free surface and surface wave of the liquid bridge were measured by the two-dimensional measurement [6—7].

For the study of fluid mechamics, velocity in an important plysical parameter. It is interested to measure the velocity of flow field in liquid bridge. The study of mumerical simulation of 3D thermocapillary oscillatory convection in a liquid bridge has been performed by Tang et al [8].

In the present paper, the Particle Image Velocimetry (PIV) method has been used to measure the velocity distribution of flow field in the liquid bridge. The velocity distribution in a horizontal cross-section of liquid bridge in oscillation state was measured in the sequential time of one period. The method of experiment will be described in next section, and then the experimental results. The last section is the conclusion.

2. Experimental method:

A liquid bridge as shown in Fig. 1 schematically has been studied for the measurement. The diameter of upper and lower rods do=6mm, the waist diameter of the liquid bridge dmin=4. 07mm and the length of liquid bridge L=3. 9mm. The silicon oil 10CST with the light scattering particles of 20μm in diameter was used for the experimental liquid medium. For this liquid bridge, its aspect ratio L/do=0. 65, and diametric ratio d_{min}/d_0=0. 68. The critical temperature difference $\triangle T_c$=34. 2°C and the oscillation frequence is 0. 5Hz determined experimentally.

The velocity distribution of flow field in a liquid bridge can be measured in both vertical and horizontal cross-section by PIV method respectively. But, it should be pointed out that the image of flow field in a vertical cross-section is distorted optically by the shape of the liquid bridge, because its lens effect. Therefore, a horizontal cross-section of flow field was measured in the way as shown in Fig. 2. A cross-section of liquid bridge is illuminated by the light-sheet of He-Ne laser in horizontal plan. The illuminated plan of flow field is focused on the CCD camera with a zoom objective lens (f=35—110mm) through a glass window mounted in the lower rod of liquid bridge and a mirror with 45° incidence angle. The image of the flow field (i. e. the particle image) is displayed on the TV monitor and recorded by VTR in time sequence. Because of no lens effect from the shape of liquid bridge, the real local velocities in the horizontel cross-section can be obtained with a sufficient measuring accuracy.

3. Experimental Results:

The particle image velocimetry records have been evaluated and the flow vector graphs are constructed by the techniqe of digital particle image velocimetry (DPIV) [9—10] in Essen university, Germany. Fig. 3 shows an example of the velocity distribution of oscillatory flow in a horizontal cross-section at a determined time. It can be seen that the flow is asymmetrical compared with the axisymmetrical flow in steady state.

For the analysis of the oscillatory flow, the flow pattern of velocity vectors have been evaluated in the sequential time of one period (about 2 seconds), and the velocities are divided into two components: the component in azimuth V_θ and the component in radius V_R. The flow structures are constructed successively in one period time of the oscillation as shown in Fig. 4 respectively. It is very interested to find that the velocity distribution of azimuthal component V_θ is composed of two parts flowing in the opposite direction with each other, and rotating in azimuth counter-clockwise at fo (the freguency of the oscillation of the liquid bridge). A source and a confluence of the flow are formed in the flow field. As the velocity of azimuthal component V_θ at those two point (the source and confluence) are assumed equal to zero (i. e. $V_\theta=0$). According to the successive flow patterns shown in Fig. 4, the volocity variation of V_θ and V_R at the typical points, for example, the source and the confluence, could be graphed with the period time as shown in Fig. 5 qualitatively. The velocity vibration of both component V_θ and V_R are in sinusoid at a proper applied temperature difference. Because, in the present experiment, $\triangle T=42.6°C$ is $8.4°C$ beyond the critical temperature difference. In this case, the oscillatory mode $m=1$ [3], the temperature and free-surface oscillation are in sinusoid [7].

The periodic flow pattern of radial component V_R variated at the freguency fo and rotated with a constant angular velocity in azimuthal direction. The periodic flow pattern of azimuthal component V_θ at the freguency 2fo and rotated with the same constant angular velocity in azimuthal direction.

According to the radical velocity vectors V_R graphs as shown in Fig. 4 (right), the oscillatory flows have an asymmetric flow pattern and forms a small stagnant region its location in the flow field is just the location of confluence as shown in Fig. 4 (left). and rotating counter-clockwise with the constant angular velocity as same as azimuthal flow.

4. Conclnsion:

The velocity distribution in the flow field of liquid bridge in osaillatory state has been measured by PIV method. The experimental results demonstrate that the PIV method has the potentiality to measure the velocity distribution of a small scale flow field with a special CCD camera lens. It is benifit to understand the oscillatory flow of thermocapillary convection in floating zone.

The velocity distribution of oscillatory flow in a horizontal cross-section of liquid bridge has been evaluated in a one period time. The graphs of velocity vectors have been demonstrated and analysed. The velocity in azimuthal deriction V_θ is an important physical parameter for studying the onset of oscillation in liquid bridge as described by Chun and Wuest [11]: The periodic change of streamline in liquid zone based on the fact that there is a thermal oscillation due to an azimuthal direction flow.

The experimantal measurement shows the azimuthal flow in a horizontal cross-section is consist of two flows, a source and a confluence are formed. They are rotating at the freguency fo in azimuthal direction.

In the presant paper, only one definited liquid bridge described above has bean studied for the measnrement of velocity distribution by PIV method. For this case, the measnrement shows that the oscillation mode $m=1$. The oscillation mode will be changed dependent on the geometrical ratio [12] of liquid bridge and gravity level [8]. It implies that more experimental studies on velocity features of thermocapillary convection in the flow field of liquid bridge should be completed. The PIV is a parctical and favorable method.

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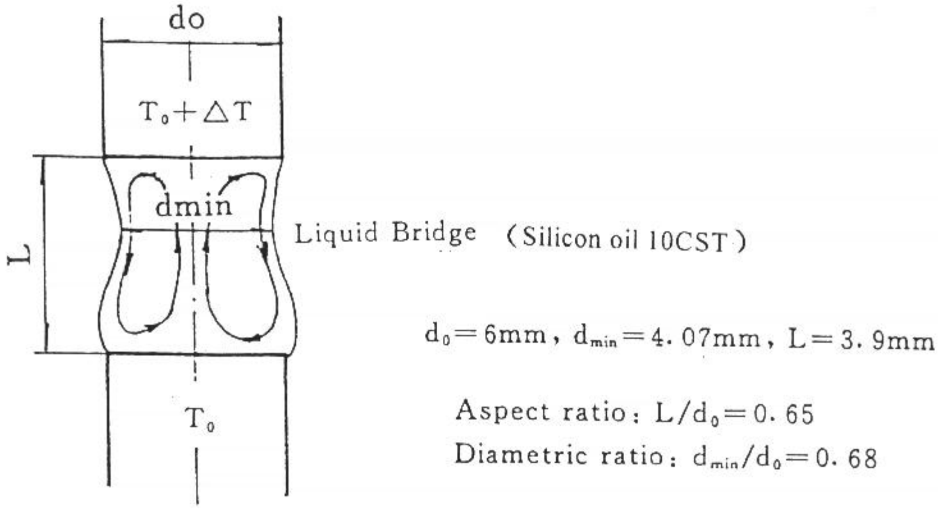

Fig. 1 The schematic diagram of liquid bridge for the measurement

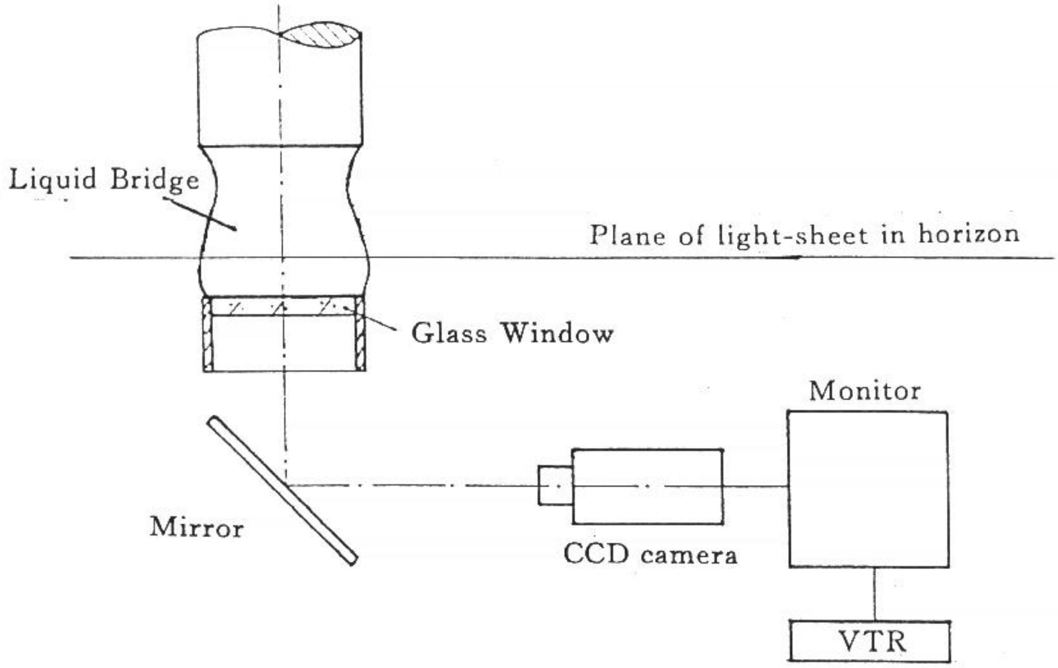

Fig. 2 The schematic diagram of experimental setup for the measurement of velocity distribution in a horizontal cross-section of liquid bridge

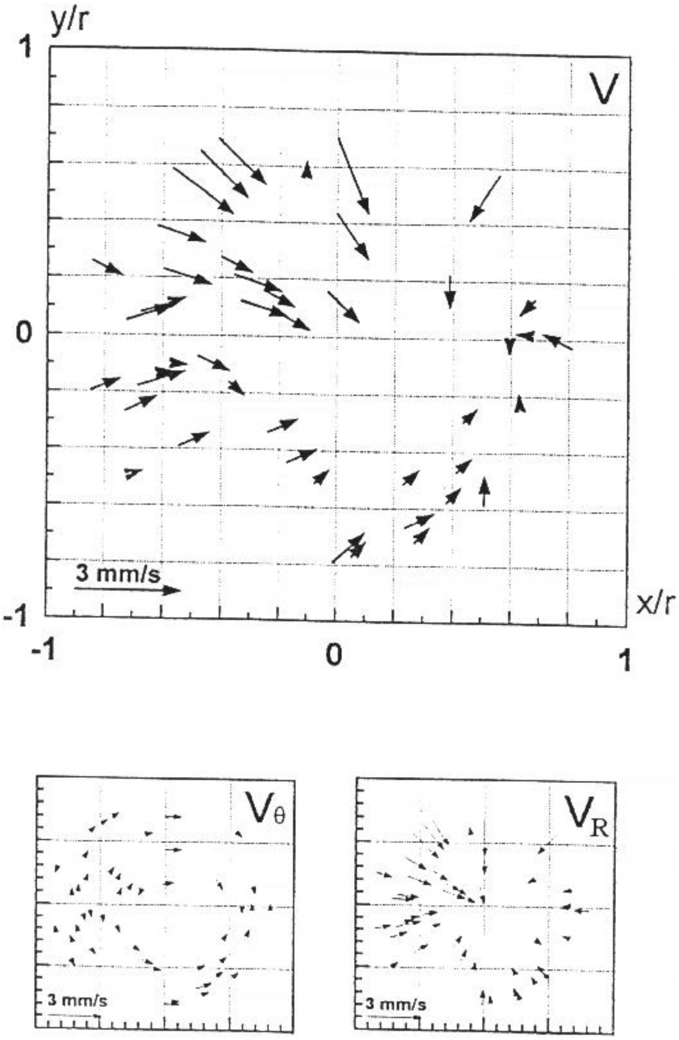

Fig. 3 The velocity vectors pattern measured in a horizontal cross-section of liquid bridge

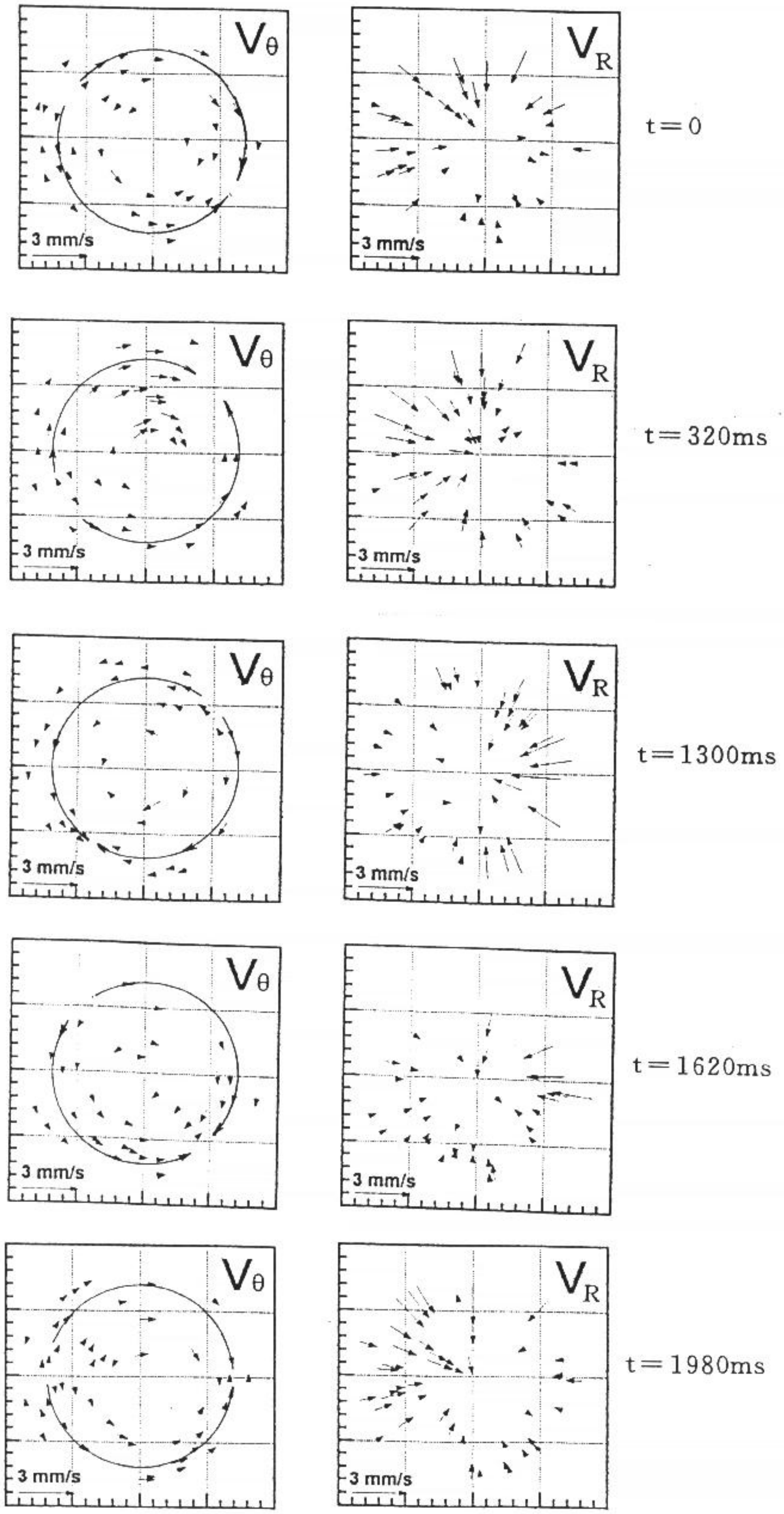

Fig. 4 The experimental flow structure of the horizontal component V_θ(left) and radial component V_R(right)in successive moment of time (t=0 corresponds to the beginning of records)

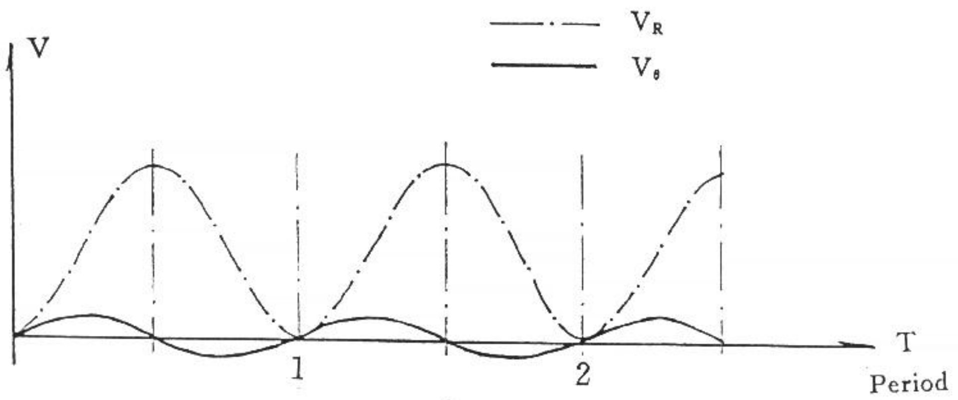

Fig. 5 The velocity variation of oscillatory (m=1) flow at the special points (source and confluence) of flow field in a horizontal cross-section of liquid bridge