Master Theses

* Measurement of Overflow by UDM
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Diploma Theses

* Bubble Behavior in a Horizontal Bubbly Channel
  M. Kakizaki
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* Mixed natural convection in a horizontal fluid layer
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  He visualized cell patterns of mixed convection and found double-cell structures.
* Oscillating Taylor Couette flow
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  He investigated flow transition modulated by azimuthal velocity perturbation.
* Flow Measurement in an Open Channel by UDM
  K. Yokoyama
  He tested the possibility of UDM-base flowmetering for environmental application.
* Fundamental study for measuring the three-dimensional velocity component by UVP
  K. Yamaguchi
  He measured sound pressure field of a focused ultrasound transducer to test a principle of a vector UVP.

Abstract

A concern over the measurement of environmental flow is increasing in, in these years. Electromagnetic current meters or propeller meters have been mainly used for measurement of environmental flow, but, these meters need a lot of time and effort to obtain information of field flow because of their measurement principle: measurement at a point. Therefore, the assumption that a flow has an ideal velocity profile for direction of depth must be used generally to estimate a discharge in a channel. In this research, UDM (Ultrasound Doppler Method) was used. This method has mainly the following advantages over the conventional techniques 1) a record of the instantaneous velocity field on a measurement line, 2) an efficient flow mapping process and 3) applicability to opaque liquids.

In this research, the target was focused on an overflow at a dam. Experiments using an open channel and a dam were performed both in Hokkaido University and in the R&D center of Tohoku Electric Power Company. The purposes of this research are 1) estimating a discharge of overflow based on velocity profiles, 2) mapping of velocity vector in overflow and 3) verification of application of this method to environmental flow. All about experiment in the R&D center of Tohoku Electric Power Company is described in chapter 5.

The coordinate system of the experiment is shown in figure 2-1. Reynolds number is defined in 2.4. The experimental setup is explained in chapter 3. The setup has a tank, a pipe, and an open channel. Test sections were on the pipe and at the dam (figure 3-2). The dam is described in figure 3-3. A quantity of water in setup is about 0 ~ 9 [l/s]. The measurement system is explained in 3.1.2. Total system is given in figure 3-4. A udFlow by TEPCO was used for measurement of pipe flow, and UVP-Duo by Met-Flow was used for measurement of overflow. At dam, transducers that emit ultrasound pulse are set as in figure 3-5 and 3-6. Using stepping motor and motor for linear motion, all region direction for *y* and *z* could be measured. The discharge in pipe was standard of quantity that was in the setup. Chauvenet's criterion[9] was used for all of data obtained by UDM.

The results of experiment are in chapter 4. Figure 4-3 ~ 4-10 are pictures of overflow. The larger Reynolds number, the more inclined the top free surface is.

Firstly a single transducer was used for measurement. Figure 4-11 is an example of velocity profiles measured by an inclined transducer. Considering measured regions (figure 4-12), it can be determined where the top free surface is in the velocity profile. Only the region "A" is used for velocity distribution and for estimation of discharge. Figure 4-13 is the cross section of measurement. Figure 4-14 ~ 4-21 are velocity distributions at the cross section. Flow velocity is small in the

regions near the surface of dam and near the sidewall. The flow velocity is the largest in the region that is closer to center of open channel than the region near the sidewall. Based on these velocity profiles, discharge was obtained. The result is figure 4-22. The reasons of differences are data processing that could not get off lacks of data completely, and limited capacity of measurement with single transducer (figure 4-23).

Secondly two transducers were used for measurement to obtain velocity vectors in an overflow. Velocity vectors were measured with 0.8mm interval for *z* direction by 15 points for *y* direction, in each condition. Figure 4-24 ~ 4-29 are velocity vector mappings at the center of the open channel. The direction of vectors is well accorded with the direction of flow. Based on these velocity vectors, velocity distributions and discharges in each condition were obtained. The results are figure 4-30 ~ 4-35 and 4-36. The trends of velocity distributions are very similar to what was measured with a single transducer. Trends of variation about discharge between at the dam and on the pipe were similar. But there were some differences about absolute values between them. The reasons of differences can be by the same data processing, or a reduction of ultrasound energy when ultrasound through an acrylic plate. But, the difference between data from measurement with a single transducer and data from measurement with two transducers is different in quality. Measurement with two transducers has possibility a lot to do measurement with better accuracy.

In the R&D center of Tohoku Electric Power Company, the similar experiment was performed. The targets of measurement are in figure 5-1 and 5-2. The measurement system is the same as in Hokkaido University, and schematics of setting are in figure 5-4 and 5-5. Velocity distributions using a single transducer in three conditions are figure 5-9 ~ 5-11. And, figure 5-14 ~ 5-22 are velocity vector mappings. The flows were represented so clearly by velocity vectors that can be imagined easily. The discharges estimated from velocity distributions with a single transducer and from velocity vector with two transducers are in figure 5-23. Of course the latter result is better, and approximately equal to discharge on pipe.

The conclusions of this research are the followings 1) a discharge of overflow can be estimated by UDM, and using multi transducers is better, 2) a mapping of velocity vector in overflow can be obtained by measurement with two or three transducers and 3) considering the results of experiments at two setups, UDM can be applied to a measurement of environmental flow.

Abstract

Natural convection in a horizontal fluid layer induced by internal heating was studied experimentally. Internal heat source is considered to play an important role in variety of convections. Only a few experiments on internal heating problem were made.

Tritton & Zarraga reported their experiment for the first time and Schwiderski & Schwab the second experiment. Two characteristic phenomena were observed in their experiments. Firstly, convection cell elongates drastically with increase of total input of internal heat generation. Secondly, flow direction in convection cell is entirely opposite to Bénard cell, namely descending flow exists at the center of the cell. Such a cell elongation, however, has been proved theoretically. Schwiderski & Schwab concluded that the cell elongation is caused by non-uniformity of internal heating. In their study, however, no physical quantity was measured to discuss the cell elongation and their hypothesis for this problem may not have enough reliability. The mechanism of the convection was yet to known fully.

We especially take notice about temperature as physical quantity for the sake of making a better explanation with quantitative discussion on this problem. Our task is to make visualization and quantification of the temperature field by using temperature-sensitive liquid crystal (TLC). Actually we expect temperature behavior to be investigated in detail with respect to Rayleigh number.

Rayleigh number is the dimensionless parameter as a control parameter of natural convection. We use the internal Rayleigh number defined as,

$$R_{\mathrm{I}} = \frac{g\beta H L^5}{2\lambda\kappa\nu},$$

while internal heating was taken into account. The boundary condition is shown in Fig. 1.10. In our experiment, internal heat was generated electrically. Ionic fluid was used for electrical heating and was a solution of potassium chloride of 0.5wt%. The electrode was the copper and AC power supply was used.

Figure 2.1 shows schematic illustration of our experimental apparatus. The fluid layer has the horizontal cross section of 210mm×210mm, and the height of the fluid layer was 7mm. Its aspect ratio Γ=30. The all sidewalls were made of acrylic resin of 10mm thick. The glass, which has the vacuum layer between two-ply glasses, was used for thermal insulation of the lower plate and visualization. A 20mm thick plate of aluminum was set on the upper surface of the fluid, and this plate was cooled uniformly by water circulated from the thermostatic bath. We set the temperature of the upper plate equally to the room temperature, so as to suppress the convection induced by the temperature difference between the upper and lower plate.

TLC visualizes convective temperature field, and was calibrated with image processing technique through the use of Hue method. All color components of visualized photographs are converted to temperature with the uncertainty of 0.253 degree Celsius in our study.

Figure 4.1 displays results of visualizations. The drastic dilatation of the convection cell with increase of R_I was confirmed and flow direction in the cell reported in the past studies was also verified by visualized temperature distribution. Fourier analysis quantified the change of wavenumber of convection cell by using brightness information of the visualized pictures. The quantified temperature field allows shape of convection cell to be determined quantitatively.

We evaluated several characteristics of the natural convection of this configuration, such as shape, size, and temperature distribution in each convection cell. A convection cell formed in the internally heated convection has an irregular shape in contrast with standard Rayleigh-Bénard convection in which roll or regular hexagonal cell is formed. The irregularity of a shape compared with a regular hexagon was estimated, and the result concluded that it is nearly constant with respect to R_I with wider extent. As already mentioned above, a convection cell elongates with respect to R_I, namely wavenumber of a cell decreases with increasing of R_I. Size of convection cell was estimated at various Rayleigh number in two ways, which are a wavenumber analysis of brightness information extracted from visualized pictures and an estimation of area of a cell on temperature field. Variations of wavenumber were obtained and the tendency of these variations is similar to the earlier study. Each temperature distribution of convection cell was investigated at various R_I, and a variation of the distribution with respect to R_I derived an influential hypothesis for a formation of “double cell structure”.

Onset of convection was detected by qualitative and quantitative method, which are an experimental observation and analyzing a temperature field. Critical Rayleigh number of this problem was determined by a variation of temperature difference on a convection cell with respect to internal Rayleigh number, and this value agrees well with that calculated by Roberts. This result confirms a reliability of realizing ideal experimental system in this study.

Abstract

The flow between coaxial rotating cylinders is called Taylor Couette flow. A flow transition in this configuration with only inner cylinder rotation was investigated using ultrasonic Doppler method for wide range of Reynolds number R up to 40 times critical Reynolds number (R_c). At very low Reynolds number, the flow is circular Couette flow (CF) that has the only azimuthal velocity component. At $R = R_c$, CF transits to Taylor vortex flow (TVF), which is three-dimensional, time-independent flow of a set of stacked axis-symmetric counter-rotating vortices alternately. On increasing R, at $R = R_w$, an azimuthal wave appears and an instability sets in, which deforms a TVF to produce a time-dependent non-axisymmetric flow that is called wavy vortex flow (WVF). Further increasing R, at $R = R_m$, any additional wave mode appears which is modulated WVF: this flow is called modulated wavy vortex flow (MWV). The energy supplied in the system by the inner wall is transferred in cascading from the CF→TVF→WVF→MWV.

We attempted inject energy to WVF mode directly by oscillating the rotation of an inner cylinder. The objective of the present investigation is to see if there is any effect of a perturbation of oscillation of the inner cylinder on the energy cascading.

Fig. 3.1.4 (pp11) shows experimental set up. The coaxial rotating cylinder system in this experiment has a radius ratio $\eta = R_i/R_o = 0.905$ (R_i is the radius of inner cylinder: 95mm, R_o is the radius of outer cylinder: 105mm), and an aspect ratio $\Gamma = h/d = 20$ (h is the height of fluid layer: 200mm, d is the gap distance: 10mm). The inner cylinder is fabricated of FRP to reduce its weight. Working fluid is 27% glycerole solution. Ultrasonic Doppler method (UDM) measures instantaneous velocity profile parallel to the axial of the cylinder. The ultrasonic basic frequency is 4MHz, and the beam diameter is 4mm. The transducer is set at the outside of the gap with its beam center located at 2mm from the outer wall. Reynolds number is defined as $R = d\Omega R_i/\nu$ (Ω is a rotation speed, ν is kinematic viscosity). Reduced Reynolds number is defined as $R^* = R/R_c$ ($R_c = 134.57$).

Oscillation of rotation speed is expressed as changing the instantaneous Reynolds number as shown $R^*(t) = R^*_0 + \Delta R^* = R^*_0\{1 + A\sin(2\pi f t)\}$. In this formula, $R^*_0 = 3$, A: oscillation amplitude, f: oscillation amplitude, and t: time. The oscillation is within a range that WVF mode exists stably, namely $R^*_{min} \geqq R^*_w$ and $R^*_{max} \leqq R^*_m$. Case of variation of amplitude; A perturbation of oscillation is given as $R^*(t) = R^*_0 + \Delta R^* = R^*_0\{1 + A\sin(2\pi f_0 t)\}$. In this formula, f_0 is a characteristic of WVF mode determined as the center frequency of main peak in the power spectrum of $R^*_0 = 3$. We changed this amplitude from $A = 0$ (0%) to $A = 0.15$ (15%). Case of variation of frequency; A perturbation of oscillation is given as $R^*(t) = R^*_0 + \Delta R^* = R^*_0\{1 + 0.07\sin(2\pi f t)\}$. We changed this frequency from $f = 0.9 \times f_0$ (90%) to $f = 1.1 \times f_0$ (110%).

Fig. 4.2.2 (pp35-pp38) shows a sequence of power spectra with respect to oscillation amplitude. For large amplitude over 9%, a new peak f_A appears at slightly higher frequency from the second harmonic peak f_2. We expected that the peak is caused by oscillation, but the effect of the weak mode on the flow is very small because the peak is very small. Fig 4.2.3 (pp41-pp42) shows variations of peak power with respect to oscillation amplitude. Peak power is area of peak. For the peak f_1, f_2, f_3, there was observed a peculiar variation of the power. The most remarkable feature of the variation of the peak power is that the dip of power occurs at the same amplitude, 11%. This dip occurs in all experiments but at different oscillation amplitude as shown in Fig. 4.2.8, (pp53). For the peak f_A, growth of the power is very weak and the amount is not sufficient to compensate the decrease of the power of f_1, f_2, f_3. Because the power does not disappear, we suppose that exchange of energy between the axial component and radial/azimuthal component occurs. Fig. 4.2.5 (pp45-pp50) shows a spatial distribution of the power of main peak, namely a space dependent power spectrum. It is seen that the peak becomes sharper for the large oscillation amplitude. Fig. 4.2.6 (pp51) shows variation of maximum peak power, and Fig. 4.2.7 (pp51) shows variation half width of peak. The peak becomes sharper and the maximum peak power increases up to the oscillation amplitude A = 11%. It indicates that energy is more concentrated on the frequency f_0 by the oscillation of inner cylinder.

Fig 4.3.2 (pp59-pp60) shows a sequence of power spectra with respect to a change of oscillation frequency. In all the cases, f_1, f_2 and f_3 appear, and another peak does not appear. Fig 4.3.3 (pp61-pp62) shows variation of peak power. Peak power is plotted with respect to change of the oscillation frequency. For the peak f_1, f_2 and f_3, peak power is maintained almost constant. We could expect the flow maintains the state of the flow that we oscillated the rotation with $A = 0.07$, $f = f_0$. Fig. 4.3.5 (pp64-pp65) shows a spatial distribution of the power of main peak with respect to a change of oscillation frequency. Fig. 4.3.6 (pp66) shows variation of maximum peak power. And Fig. 4.3.7 (pp66) shows variation half width of peak. The width of the peak and maximum peak power does not vary by oscillation frequency. It indicates that energy is not concentrated.

In conclusion: Direct energy injection to the WVF mode is not realized by this method. In case of variation of oscillation amplitude: A new peak f_A appears, but the effect of this mode on the flow is very small. The variation of the peak power of WVF mode shows a dip at 11% of the oscillation amplitude. This result may suggest us that the energy of the axial velocity component would be transferred to the radial or the azimuthal velocity component. However the oscillation amplitude that the dip occurs is not definite. Peak power of WVF mode is more concentrated on the frequency f_0. In case of variation of oscillation frequency: The flow maintains the state of the flow that we oscillated the rotation with $A = 0.07$, $f = f_0$.

Abstract

Various methods have been used for measurement of the flow velocity, for example HWA, LDA and so on. Ultrasound Velocity Profiler (UVP), which uses ultrasound wave, is an especially powerful tool to measure a velocity field because it obtains an instantaneous velocity profile along the measuring line easily. Moreover, an ability of determining a velocity profile in an opaque fluid is an advantage over the optical techniques such as LDA and PIV. There are two kinds of fundamental algorithms for UVP, namely the conventional pulse Doppler method and “Correlation method”, which recently has been devised in order to measure high-speed flow. Both methods, however, have merits and demerits for each other.

As the main subject of this thesis, an effective method is worked to measure the very low speed flow velocity, less than mm/s, such as velocity occurring in a natural convection. In ordinary methods of UVP, pulse Doppler method and correlation method, Fourier transform and a correlation function are used on a digital process. There is, of course, a countable limit for the minimum measurable velocity because the flow velocity is calculated as discrete value, which induces a limit of the low velocity measurement. Therefore the method on UVP without velocity resolution is proposed.

The proposed algorithm in the main subject computes velocity by acquiring the phase difference of a received wave. As an example, there is a picture of a face. The picture should move its location after a time of *dt*. Although the moving distance is usually calculated in considering the picture as a whole, the moving distance of each composed element can be calculated by considering that the picture consists of two or more composing elements by this algorithm. If the picture consists of elements called a face outline, a right eye, a left eye, and a mouth, this moving will not be interpreted as "The picture itself moved", but be interpreted as "Each element moved in the same distance and the same direction". Therefore, the move distance is computed about main elements, which is easy to evaluate for velocity. When this concept is applied to signal possessing, a picture of a face represents a received data and each component is equivalent to frequency component that is calculated by FFT. A phase difference can be known in each component. A moving distance can be calculated with this phase difference.

This algorithm can measure closely zero velocity and has no theoretical velocity resolution. Simulation estimates statistical limit of minimum velocity. A signal is produced on a computer, and is quantized mathematically. Another signal is sifted, and be quantized as well. These two signals are calculated, and velocity is computed. The quantization is an essential factor of setting the limit of velocity. It is,

however, difficult to formulate a relation between quantization and a velocity error.

A model flow, a rotational flow, a flow around a heat bar and a Rayleigh-Benard convection were measured in this experiment to confirm the ability of this algorithm. A model flow is not a real flow. Six strings are set in water. While a transducer moves, it emits a burst and received the reflected wave from the strings. In this case, analysis is relatively easy since the power of reflected wave is much stronger than from particles, such as glass beads. Moreover a computer can control speed. A rotation flow shows a velocity profile theoretically. The cylinder filled with water is located in the center of the tank and rotated. In this system, a velocity of water in the cylinder in measured. Analyzed velocity can be compared with theoretical velocity. To estimate an ability of measuring system, applying rotation flow is a better way. A heated bar is located in the cylindrical tank filled with water. The bar is heated by an electrical current, and flow is generated around the bar. This system measures a flow of natural convection around the bar. This flow is actually an unsteady flow since the experimental condition is not perfect. A simulation shows a velocity profile around a heat bar. Therefore, a measured result can be compared the theoretical profile. A Rayleigh-Benard convection is generated in glycerin by circulating cold water and warm water from thermostatic chamber in the upper part and the lower part. The temperature of cold water is 10 degrees and the temperature of warm water is 50 degrees. A natural convection can be observed with this equipment. The flow observed with this equipment has the lowest speed in this investigation. In this experiment, this convection is steady because Rayleigh-Number is 19610, Plandtl-Number is 1.04×10^4. This equipment was provided by Dr. Yanagisawa of Japan Marine Science and Technology Center.

The measured results showed a profile as expected for the Rayleigh-Benard convection. This indicates that the present algorithm works fine for the very low velocity field. It was, however, not possible to evaluate the accuracy of measurement since velocity value is not known.

This research examined the new algorithm for measuring an instant velocity profile of the low flow velocity using an ultrasonic wave. This algorithm itself has theoretical validity and this can also measure the nearly zero velocity. As for the proposed algorithm, the minimum value of velocity is not determined by resolution. This is an important point to measure a very low flow. Therefore, this research can be expected that, since this new algorithm can measure a velocity at an opaque flow, an unsteady flow and a very low flow, it can meet many requirements, such as improving production and sanitary management, which is accomplished after understanding fluid process in manufacturing processes.