A flow visualization method entitled Digital Vector Velocimetry (DVV) method is introduced to extract the flow field quantitatively from particle images. This method is applied to a lid-driven rotating cavity flow. In the DVV method, a time sequence of images are captured by a CCD (Charge Coupled Device) video camera with each frame containing a single-exposure image. All possible velocity vectors between two temporally successive images in the interrogating window are digitally constructed on the digital vectorgram. The most probable velocity vector is identified as the velocity vector of the maximum intensity in the digital vectorgram. The DVV system provides measurement with subpixel accuracy. The dynamic range of the velocity is expanded using feedback analysis that selects consistent velocity vectors.

Key Words: Quantitative Flow Visualization, Rotating Flow, Digital Vector Velocimetry Method, Particle Image Processing

1. Introduction

Flow visualization has been an important tool in observing the fundamental characteristics of a flow field. Flow visualization helps us comprehend the structure of flow motion directly and instantaneously at multiple points. Conventional flow visualization methods, such as dye tracers, hydrogen bubble, and smoke, are limited to qualitative analysis. Review of qualitative flow visualization methods can be found in several literatures (Merzkirch, 1987, and Yang, 1988). In order to obtain quantitative data, measurements using laser Doppler velocimetry (LDV) and hot-wire anemometry can be made at single points. For the steady flow these measurements can be taken repeatedly at different locations to construct the whole velocity field. However, the point-by-point measurement to obtain the data for the whole velocity field is very tedious and time-consuming. If the flow is unsteady, such an attempt becomes very difficult or almost impossible. However, with the recent advance in computer and imaging technology, it has become possible to utilize various techniques with digital processing algorithms to obtain quantitative flow information. An overall view of quantitative flow visualization methods is available in several literatures (Hesselink, 1988, Adrian, 1991 and Chen et al., 1993).

In the present study a quantitative flow visualization method entitled Digital Vector Velocimetry (DVV) method (Kim, 1991) is introduced and applied to a lid-driven rotating cavity flow. In order to measure the velocity from particle images by the DVV method, a time sequence of images are first captured by a CCD (Charge Coupled Device) video camera with each frame containing a single-exposure image. Given a small interrogating window, many velocity vectors may be drawn between two temporally successive images by linking any two particles from the initial image to the following image. These digital velocity vectors may be constructed on a diagram where all the initial particle images are moved to the origin of the diagram. This diagram is called the digital vectorgram. Then the most probable velocity vector can be determined by identifying the position of the maximum velo-
ity intensity in the digital vectorgram. Unlike most of the quantitative methods that need optical postprocessing or complicated statistical method to analyze the image taken, the DVV method invokes the direct count of the most probable digital vector. It can be implemented without much computation effort and additional optical system.

In this study the DVV method is employed to measure the velocity field in rotating flows. The selection of rotating flows for the study is because they have important fluid mechanical applications in turbines, turbomachineries, hydraulic pumps, cyclones, bearings, and swirling in separators. Rotating flows in these devices are in general three-dimensional and highly rotational. The rotating flow fields are difficult to measure due to curved geometry normally associated with the rotating flow. In this investigation the lid-driven rotating cavity flow in the laminar region with Reynolds number of 3200 is qualitatively visualized by the digital vector velocimetry method. The experimental data obtained from the DVV method are quantitatively compared with the numerical results simulated by the finite analytic (FA) method. The comparison reveals good agreement except in the region where the velocity gradient is large within the interrogating element.

2. Experimental System

The major components include (1) test section, (2) light source and optics, (3) light-scattering particles in a test fluid, (4) recording medium, and (5) image processing system. A typical experimental setup is shown in Fig. 1.

2.1 Test section

The basic geometry selected for the present study is a cylindrical cavity with the top lid driven to rotate at a steady angular rotation of 10 rpm. Detailed drawing for the test cell for the lid-driven rotating cavity flow is given in Fig. 2. Plexiglas pipe with 127 mm inside diameter and 12.7 mm thickness is used as the cylindrical wall of the test section. In order to minimize leak between the lid and the cylinder wall, a lid with 25.4 mm thickness is used and the gap between the lid and the top of cylinder wall is kept as small as practically possible. In the present study we set the gap as less than 1 mm. The lid-driven disk was constructed such that the gap between the lid and the side of the upper wall is given as 1 mm so that disturbance due to the gap and the