Proceedings of 2004 Korea-Japan Joint Seminar
on Particle Image Velocimetry
POSTECH, Korea, Dec. 9 - 10

Dynamic PIV Measurement of Swirl Flow in a PC Fan

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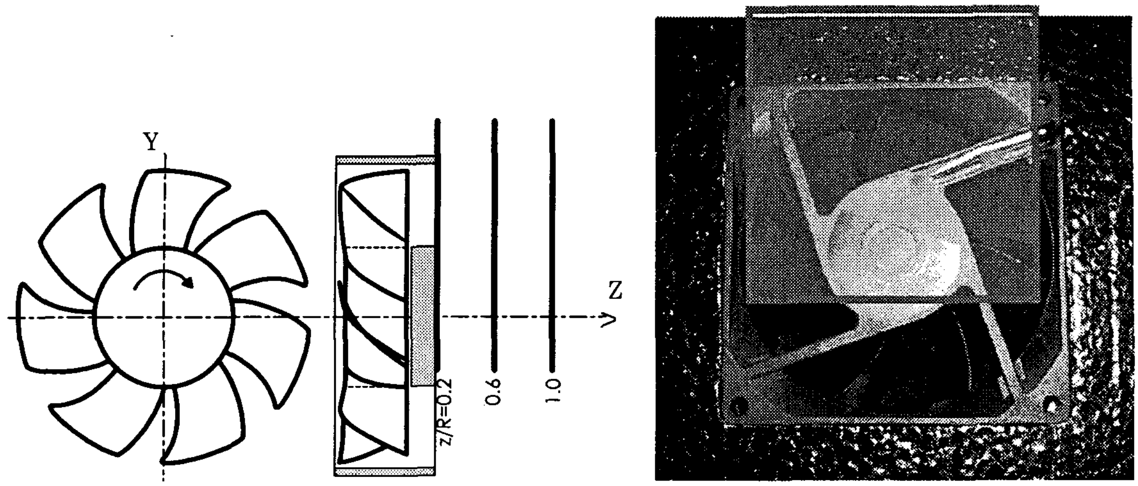
Abstract: The dynamic particle image velocimetry (PIV) is consisted of a high frequency pulse laser, high speed cameras and a timing controller. The three velocity components of flow downstream of an axial flow fan for PC cooling system are measured using the dynamic PIV system. An Axial flow fan has seven blades of 72 mm in diameter. The rotating speed is 1800 rpm. The downstream flow is visualized by smoke particles of about 0.3-1 μm in diameter. The three-dimensional instantaneous velocity fields are measured at three downstream planes. The swirl velocity component was diffused downstream and the change in time-mean vorticity distribution downstream was also discussed. The spatio-temporal change in axial velocity component with the blades passing is recognized by the instantaneous vector maps. And the dynamic behavior of vorticity moving with the rotating blades is discussed using the unsteady vorticity maps.

Keywords: Dynamic PIV, Stereoscopic PIV, Axial flow fan, PC fan

1. Introduction

PIV can capture velocity vector fields with high spatial resolution. Two-dimensional and two velocity component (2D2C) PIV and stereoscopic PIV (2D3C) systems have been commercialized. PIV systems are now widely used for fluid flow measurement applicable to low speed up to even high speed flow, including flows in a high speed rotating impeller, using a double-pulse and double-frame PIV system, large-scale to micro-scale flows, using so called a micro PIV, and so on. Because of limit of the camera's readout time and laser repetition frequency, these PIV systems can measure the flow field at 15 Hz or less (Hayami et al., 2003a, 2003b, 2004). A dynamic PIV system with 2 kHz at mega-pixel frame and up to 10 kHz at 512 x 256 pixels has been developed in success, based on the combination of a high-speed CMOS camera, a high-speed single-rod Nd: YLF laser and an in-house timing controller (Hayami et al., 2003a). Adding another CMOS camera, a stereoscopic PIV system has been constructed with a pair of Scheinmpflug position devices (made in-house) (Hayami et al., 2004).

The sampling rate of the general PIV measurement system is about 15Hz. It is difficult to measure a spatio-temporal velocity distribution when this PIV system is applied to the velocity measurement around an axial flow fan. It is possible to measure dynamic three components velocity distribution dynamically by using so-called a dynamic PIV system which combines two high-speed cameras (Photron, FASTCAM-APX) with a high repetition pulse laser (Coherent, Evolution30DPO). The present high speed camera is able to capture 1k x 1k pixel images at 2 kHz and 512 x 512 pixel images at 6 kHz (Hayami et al, 2003a). In the present paper, the stereoscopic dynamic PIV system has been applied to the swirl flow in an axial flow fan for a PC cooling system.



(a) Three measurements cross sections (b) Image position to an axial flow fan

Fig.1 PC Fan and the Measurement Position.

2. Experimental device and terms of experiment

The present system consists of two high-speed cameras, a laser light source with an optical fiber and a lens unit to supply a light sheet, and a pulse timing controller. The test PC fan is 72 mm in diameter and it has 7 blades, and it rotates at 1800 rpm. The measurements were conducted at three cross sections at 0.2, 0.6 and 1.0 times of fan tip radius from the blade trailing edge. The test PC fan and these measurement sections are shown in Fig.1. The measurement area is as a gray zone in Fig.1(b). Liquid particles of 0.3-1μm in diameter were used as tracer particles using a commercialized smoke generator (Dainichi, PORTA SMOKE PS-2001), and they were supplied from the inlet of PC fan. Image acquisition is done in the frame straddling mode of 512 x 512 pixel at 1.5 kHz. The time interval of pulses is 71.8μs. Two cameras are set at 15 degree respectively from the center axis of PC fan. Laser light sheet is 1 mm thick. Image resolution is 122 μm/pixel. The sampling timing of images is independent with the fan blade phase. A velocity vector was analyzed using commercialized software (Dantec Dynamics, FlowMap). The interrogation area is 16 x 16 pixels, and the adaptive cross correlation method is used.

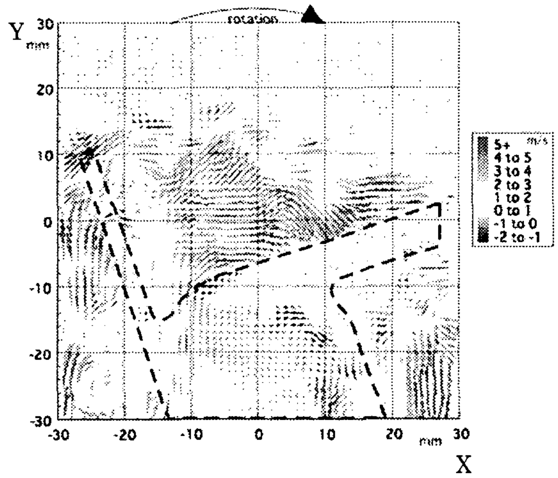


Fig.2 Instantaneous Velocity Map.(z/R=0.2)

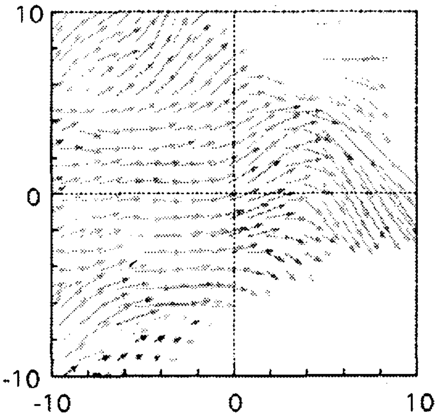
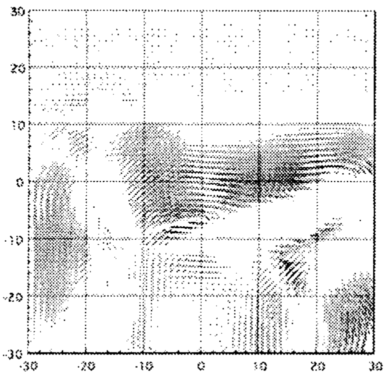
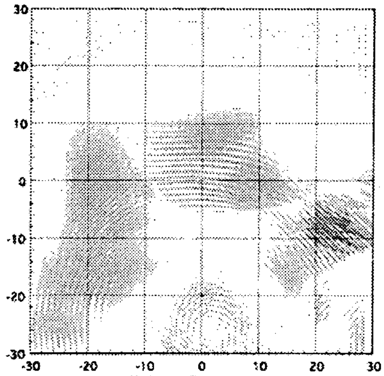


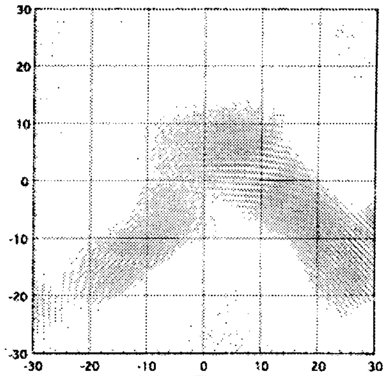
Fig.3 Expansion of Instantaneous Velocity Map. (z/R=0.2)



(a) z/R=0.2



(b) z/R=0.6

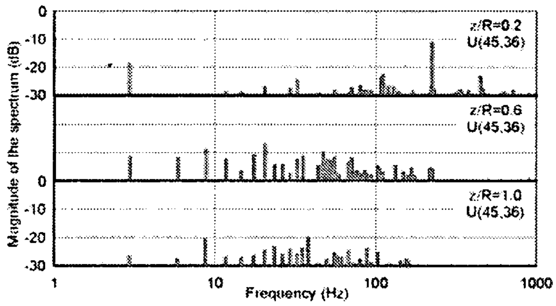


(c) z/R=1.0

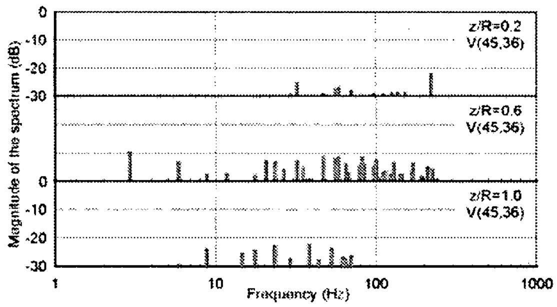
Fig.4 Time-mean Velocity Vector Maps

3. Results and discussion

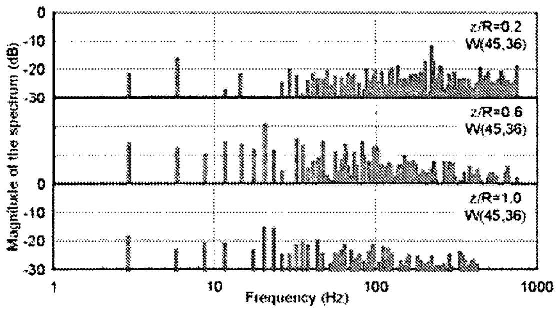
Instantaneous three-component velocity vector map at z/R=0.2 is shown in Fig. 2. The direction of a fan blade rotation is clockwise. Velocity vectors in the plane are shown as arrows and axial component velocities by colors. The red color zone shows the downstream flow as a jet, while the blue color zone indicates a reverse flow zone. A dotted line shows the position of the hub and the supporting stems for the fan motor. The stem of right side is wider than the other stem due to electric cables in the stem. The velocity around at coordinate (20,-10) region is stagnant flow zone affected by the thick stem. The velocity vector distribution map near the central part of Fig.2 is expanded in Fig. 3. The time-mean velocity vector maps at z/R=0.2,0.6,1.0 are shown in Fig. 4. These maps are calculated by 750 instantaneous vector maps during 1 second. The blade phase is not considered. As a result, the effect of stationary stems is significant, especially to z/R=0.2. As flowing downstream, Even though the effect of stems as significant at z/R=0.2 just downstream of stems, the existence of stems dose not affect on the downstream flow at z/R=0.4 as well as 0.6. On the other hand, the effect of stems is no longer recognized at z/R=1.0, due to diffused jet. As well as,



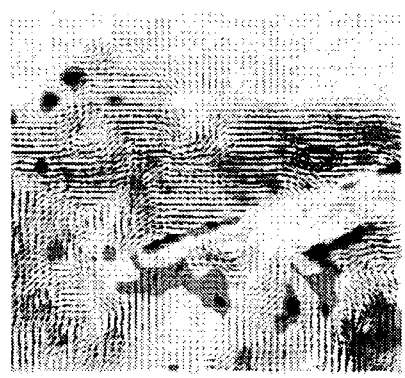
(a) X direction component spectrum



(b) Y direction component spectrum



(c) Z direction component spectrum



(d) Position of the select velocity vector

Fig.5 Spectrum of a change in time of three components velocity vector and position.

the hot color zone of the left side in z/R=0.2 and 0.6 which is fast at the both circumferential and axial velocity is no longer recognized at z/R=1.0.

The velocity spectrum calculated from a change in time of three components velocity vector at one position shown as 5(d) black circle in Fig.5. Frequency is shown in the horizontal axis, and the magnitude of the spectrum for each velocity vector components is shown in the vertical axis. A predominant peak is recognized at 210 Hz in frequency at z/R=0.2 in all three velocity components, even though it is not clear as much in Y or Z component compared with X component. For the vorticity map, this kind of peak is also recognized clearly. This is due to the wake of blade and/or the vortex issued from the blade and it rotates with the blade. That is, the dynamic PIV is possible to catch the swirling vortex.

Figure 6 shows the history of vorticity map at three cross sections. The red color zone shows the vorticity of counter-clockwise rotation, while the blue color zone indicates the vorticity of clockwise rotation. Vorticity at the select position in Fig.6 is periodically occurred at z/R=0.2. Although many vorticity are occurred at z/R=0.6, these appearance is not periodical. Vorticity of z/R=1.0 are small strength and random appearance.

4. Conclusion

Stereoscopic three components flow velocity measurement of the downstream flow in a PC fan was done using the dynamic PIV system. The effect of the hub and a hub support stem was significant on the downstream flow, and it could confirm that a great effect was being given to circumferential velocity component as well as an axial velocity component. And, it was recognized that the effect of the support was no longer left in the axial velocity component in z/R=1.0. The spectrum of each velocity component was analyzed to confirm characteristics in a change in time of the instantaneous velocity vector. A frequency of domination spectrum could be recognized to agree with the blade passing frequency at z/R=0.2. This phenomenon could be recognized in vorticity

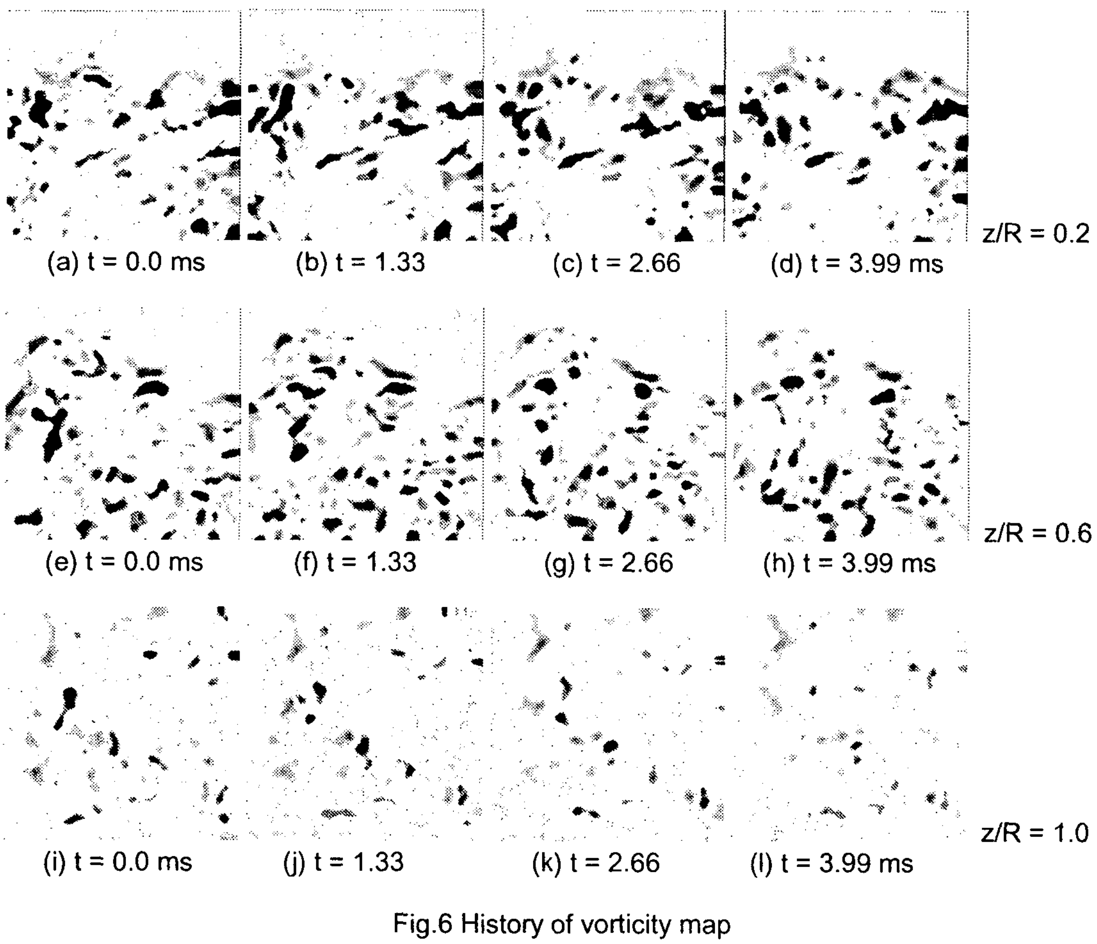


Fig.6 History of vorticity map

maps.

This research was supported by a Grant-in-Aid (No.14205031) for Scientific Research by Japan Society of Promotion for Science.

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