Performance and Internal Flow of Contra-Rotating Small-Sized Cooling Fan

Toru Shigemitsu, Institute of Science and Technology, Tokushima University, Tokushima, Japan,
Katsuhiko Hirosawa, Graduate School of Advanced Technology and Science, Tokushima University, Tokushima, Japan,
Hiroaki Fukuda, Graduate School of Advanced Technology and Science, Tokushima University, Tokushima, Japan

Long Abstract

Introduction

Data center has been built because of spread of cloud computing, establishment of ubiquitous networking society and increase of electric parts in machines. Then, electric power consumption in data centers, IT devices and machines has been increasing significantly[1]. Electrical power used for cooling of IT devices for data centers is huge the same as that used for IT devices itself in data centers. From the viewpoint of the global warming and energy savings, there is a strong demand for the reduction of power consumption in above facilities and equipment. High pressure and large flow rate small-sized cooling fans are used for servers in data centers and there is a strong demand to increase its performance because of increase of quantity of heat from servers. Therefore, high rotational speed design is conducted, and rotational speed over 10,000min^{-1} is employed for cooling fans of servers. Contra-rotating rotors have been adopted for some of high pressure and large flow rate cooling fans to meet the demand. The company's research and development period for the contra-rotating small-sized cooling fan is short and its internal flow condition is not clarified well. Therefore, the internal flow condition were investigated by the numerical analysis.

In the present paper, pressure curves of the contra-rotating small-sized cooling fan with a 40mm square casing are shown by the experimental. Furthermore, the influences of the geometrical shape and design specification of the contra-rotating small-sized cooling fan on internal flow condition are clarified by the numerical analysis.

1. Experimental Procedure and Numerical Analysis Conditions

The test contra-rotating small-sized cooling fan(R40W-A) is shown in Fig.1. The rotors of R40W-A was set in the 40mm square casing, and a hub tip ratio of the front and rear rotors were D_{hf}/D_{tf}=25mm/37.2mm=0.67 and D_{hr}/D_{tr}=26mm/37.2mm=0.70 respectively. The design flow rate was Q_d=0.55m^3/min and a tip clearance was c=0.6mm. The design rotational speed of the front and rear rotors of R40W-A were extremely high as N_f=15000min^{-1} and N_r=14000min^{-1}. Figure 2 shows a schematic diagram of an experimental apparatus. The experimental apparatus was designed based on the Japanese Industrial Standard and air blown in the test section passed the rotors, a chamber, a measurement duct and a booster fan and blew out in the ambient atmosphere. Each rotor was driven by a brushless motor set inside of the hub and the motor was supported by spokes connected to the casing. The rotational speed of each rotor was kept constant (N_f=15000min^{-1}, N_r=14000min^{-1}) by PWM control using a function generator when a performance test was conducted. Fan static pressure (ΔP) was measured by the pressure difference between the static holes downstream of the rotor installed on the chamber and ambient air. Further, the rotational speed was evaluated using a pulse of the motor measured by an oscilloscope. The flow rates were measured by an orifice meter set at the measurement duct and the pressure curves from a cutoff flow rate to the maximum flow rate were investigated in the experiment.

The commercial software ANSYS-CFX16.2 was used to investigate the flow condition which couldn't be measured by the experiment and three dimensional unsteady numerical analysis was conducted. The numerical domains comprised the inlet, rotor, chamber and outlet duct regions. The tip clearance was kept 0.6mm as the same with the experimental apparatus in the numerical analysis. At the inlet boundary, the constant flow rate was given and the constant pressure was given as the outlet boundary condition. The coupling between the front and rear rotors was accomplished by the transient rotor stator. Standard wall function and LRR Reynolds Stress model was used as a turbulence model. Time step number per one rotor rotation was 140 and the time step was t=2.857×10^{-5} s. Data of one rotor rotation were obtained after 10 rotor rotations in the unsteady numerical analysis.

2. Performance and Internal Flow

The pressure curve of R40W-A obtained by the experiment at the design rotational speed (N_f=15000min^{-1}, N_r=14000min^{-1}) is shown in Fig.3. A horizontal axis is flow rate Q and a vertical axis is fan static pressure ΔP_s. The test fan showed the negative slope of the pressure curve from the design flow rate Q_d=0.55 m^3/min to the maximum flow rate Q=1.08 m^3/min and the maximum fan static pressure ΔP_s=510Pa was obtained at the design flow rate Q_d=0.55 m^3/min. A positive slope of the pressure curve appeared from a partial flow rate Q=0.50 m^3/min to the design flow rate Q_d=0.55 m^3/min. After that, the pressure curve became flat in partial flow rates region Q=0.35-0.50 m^3/min. Then, the positive slope of the pressure curve appeared again in partial flow rates region Q=0.25-0.35 m^3/min. The flow rate became unstable and vibration of the circuit duct and large noise were generated in the flow rate range showing the positive slope of the pressure curve. It was confirmed that the operating conditions of the test fan were in severe condition as the design fan static pressure was set extremely high and the design flow rate was near the flow rate range with the positive slope of the fan static pressure curve. The internal flow of the contra-rotating small-sized cooling fan was investigated by the numerical analysis. The unsteady flow condition of the test cooling fan will be discussed in the paper based on the velocity vectors, streamlines, pressure distribution obtained by the numerical analysis.

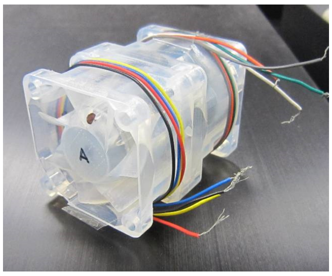

Figure 1. Picture of R40W-A

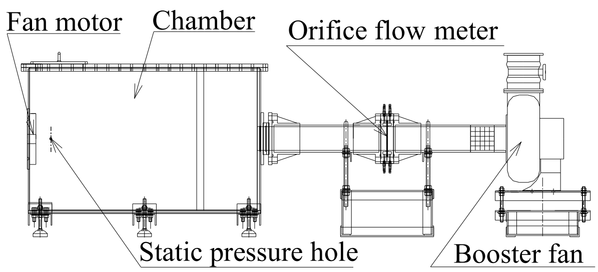

Figure 2. Schematic diagram of experimental apparatus

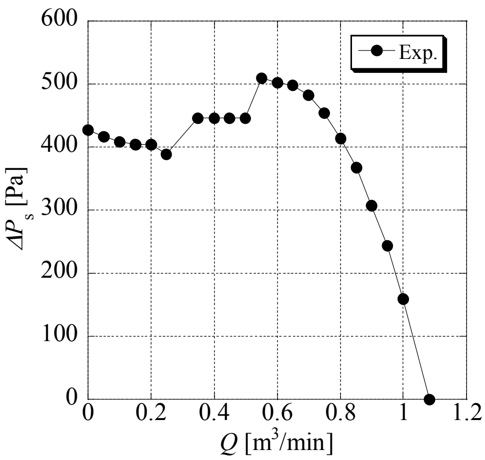

Figure 3. Static pressure curve

References

[1] Hata, T and Nakamoto, S., 2010, “Energy Saving Service for Data Centers”, Journal the Japan Society for Precision Engineering, Vol.76, No.3, pp.272-275.