Experimental study on air velocity uniformity of Equipment-Fan-Filter units

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ABSTRACT: This paper introduces the equipment-fan filter units (EFU) and analyzes the characteristics. Five modules samples of FFU and EFU are tested on the FFU performance test bench. Contrast shows that, there are significant variations of air velocity uniformity between the two, the central-regional velocity profiles of EFUs are worse than FFUs.

INTRODUCTION

Over the last decade, Fan-Filter Unit (FFU) has been widely used. Because of higher cleanliness class is required for specific equipment or clean areas after the formation of clean areas in the clean room, using standard modulus of FFU cost relatively expensive. Thus, manufacturers simplified the design of FFU which was used on equipment. To refine the distinction, the simplified FFU was called as Equipment-Fan Filter Unit (EFU).

As simplified FFU product, EFU is made of thinner and lighter plates like aluminum of which weight and casing thickness is only about half FFUs (casing thickness of EFU product is less than 150mm generally) while casing of FFU is made of aluminum plates normally. Internal structure are similar both the two, flow passage of EFU is simplified and the filter of which is ULPA usually. EFU can be installed in small place where FFU cannot and is convenient for production and installation. Currently, the offer of EFU products is about 60% of the same module size of FFU. Using EFU products bring significant economic benefits in large projects where thousands of FFU on equipment are required.

FFU/EFU EXPERIMET ON air velocity UNIFORMITY

Five different modulus of FFU and EFU samples in this experiment were from a manufacture of Suzhou, China, sizes of which are 1175mm×575mm×304mm (modulus is 4ft×2ft, denoted as 42#F), 1175mm× 1175mm×304mm (denoted as 44#F), 1167mm×572 mm×186mm (denoted as 42#E), 1167mm×1167mm ×186mm (denoted as 44#E) and 1600mm×800mm× 186mm (Custom size, denoted as CS#E) respectively. Each sample above comprises filter, 220V single phase DC brushless motor, backward vane. The speed is controlled and displayed by the console.

In clean room, FFU is mounted on the ceiling which is supposed to overcome certain external static pressure (ESP), differ from FFU, EFU is installed in the clean room environment so that the ESP is 0 generally. In this experiment, ESP of FFU was set at 90Pa, ESP of EFU was set at 0, except ESP of CS#E was set at 40Pa based on customer needs. To reduce the influence of error caused by filters and to obtain a more intuitive experiment results, same kind ULPA filters of EFU and HEPA filters of FFU were used in this experiment. Parameters of filters are shown in Table1.

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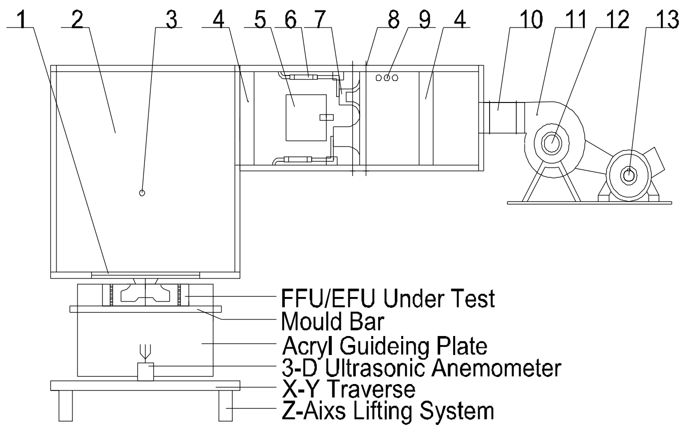
Table 1. Filter technical parameters of FFU& EFU

Sample NO.	Filter Type	Filter size (mm)	Efficiency	Initial pressure
42#F	HEPA	1167×567×75	99. 995% @0.3um	95Pa, 0.35m.s^{-1}
44#F		1167×1167×75		
42#E	ULPA	1167×572×50	99. 9999% @0.1um	115Pa, 0.35m.s^{-1}
44#E		1167×1167×50		
CS#E		1600×800×50		

Experimental Equipment

Experimental equipment is shown in Figure1, this is FFU performance test bench, Samples were installed horizontally below the plenum in which hydrostatic pressure sensor was installed so that static pressure can be controlled by motor speed and valve opening through the console.

This equipment includes following experimental conditions: (1) Air admission volume and back pressure of FFU can be regulated by electrical frequency control and butterfly valve opening degree adjustments; (2) Air admission volume can be measured by eight pressure sensors around the nozzle mounting plate; (3) FFU residual pressure can be measured and calculated by six pressure sensors in the static pressure box and atmospheric sensor; (4) Temperature and humidity sensors can monitor air inlet condition; (5) Acrylic plates compartments prevent inside FFU from environmental airflow impact; (6) Air admission volume measurement can be converted to standard condition by real-time monitoring of temperature and humidity data; (7) air velocity at FFU outlet section can be measured by displacement of ultrasonic anemometer within XY plane which can be accurately controlled by three-dimensional electric shift platform and the accuracy of anemometer is ±0.1%; (8) Combination of four nozzles (D=3ft×1, D=4ft×1, D=5ft×2) can meet various tests of each air volume of which error is 2%[1].



1 Samples mounting opening 2 Plenum 3 Pressure sensors(six) 4 Flow homogenizer 5 Maintenance inspection opening
6 Air pressure switch of nozzle 7 Nozzle（3+4+5inch）
8 Differential pressure sensors of nozzle(eight) 9 Temperature, humidity, atmospheric pressure detection sensor 10 Flexible connector 11 Turbo fan 12 Butterfly valve 13 Motor

Figure1. FFU& EFU Performance Test Bench

Experiment Method

In the experiment, each sample was tested at different mean air velocity, target test mean velocity ranged from 0.2m/s to 0.6m/s (initial velocity was 0.2m/s with 0.05m/s increments). Motor speed of FFU& EFU was adjusted by the controller to approach target test velocity of each sample and then data was recorded (nozzle flow, motor speed, air velocity at measuring points).

FFU& EFU were horizontally mounted on the mound bar under the plenum and outlet pressure of which was atmosphere therefore the static pressure was 0. By varying valve opening and the motor frequency static pressure of plenum was adjusted so that external static pressure regulation can be achieved for each sample. Then, under different air velocity, displacement of ultrasonic anemometer probe points were controlled to measure air velocity V_i at different locations in the plane which was 50mm vertical distance far from the filter outlet. 6×6=36 measuring points were picked for 44#E and 44#F while 6×3=18 points were picked for other samples. Mean air velocity is

$$\overline{V} = \sum_{i=1}^{n} V_i / n \tag{1}$$

air velocity uniformity was evaluated by air non-uniformity[2]:

$$NU = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(V_i - \overline{V})^2} / \overline{V} \tag{2}$$

Experimental results of air velocity uniformity

Curve in Figure2 shows variation with mean velocity of air velocity non-uniformity. Seen from the figure, uniformity of each sample deteriorate with the increase of mean velocity, wherein uniformity of 42#F 44#F and 42#E variate less of

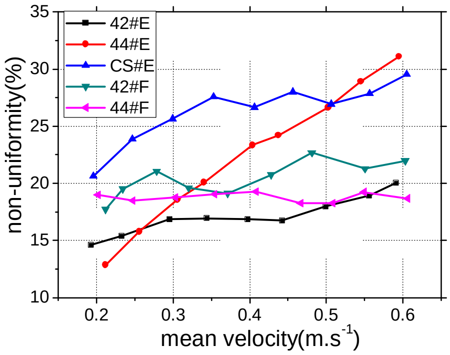


Figure 2. Variation cure with mean velocity of air velocity non-uniformity

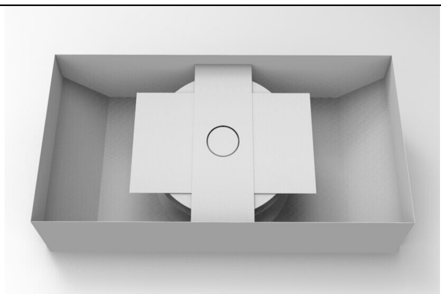
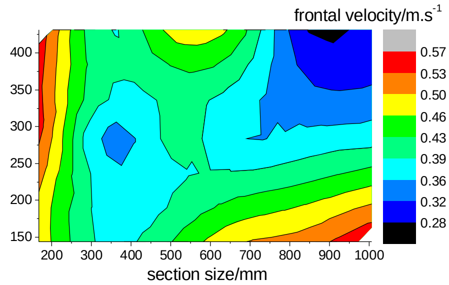
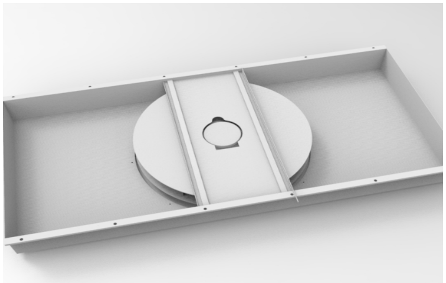
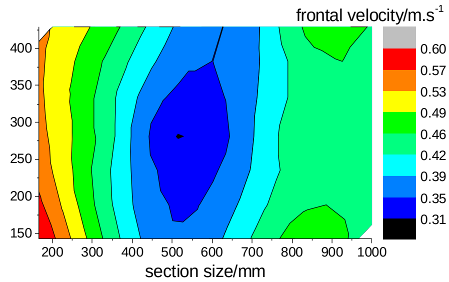
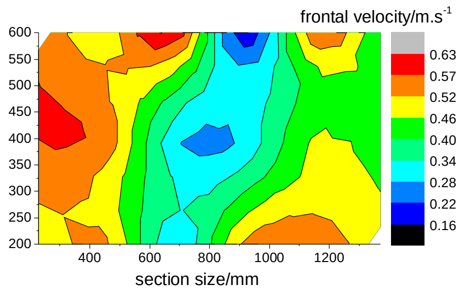
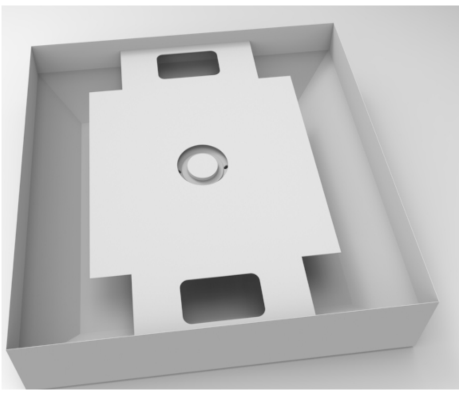
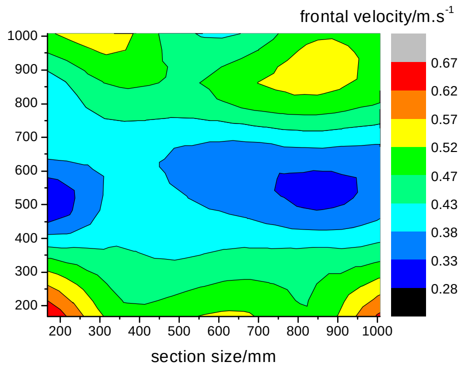
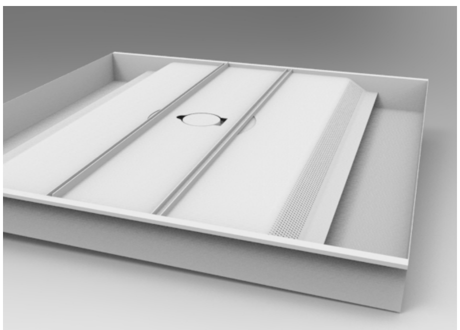
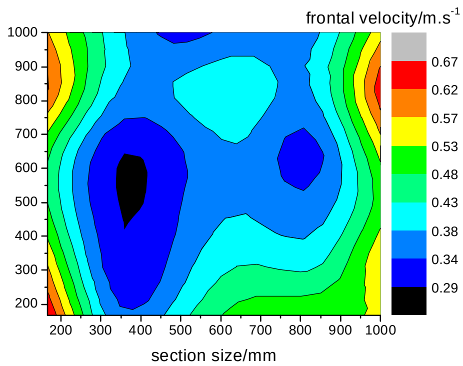
which have stable performance, air non-uniformity of 44#E and CS#E is relatively higher while air non-uniformity 44#E raise rapidly with increase of mean velocity. Under 0.45m.s^{-1} working condition, uniformity of CS#E performs worst while 42#E is the best.

Internal cavity between vane and filter known as antechamber of filter which acts as a plenum[3]. Study[4] introduces that bigger plenum and larger outlet area help to improve the air supply uniformity. This law explains why uniformity of 44#F is significantly better than 42#F as shown in the figure above. However, the EFU samples do not strictly follow the law which suggest that the impact of the internal structure of EFU on uniformity should be considered.

Under 0.45m.s^{-1} working condition, internal structure of different samples and the corresponding velocity profiles are shown in Table2. There are obvious difference between FFU and EFU internal structure design: (1) Casing of EFU sample is extremely thin which causes a quite low height between filter to base plate of the motor, so the antechamber volume of filter is very small; (2) Each EFU sample is equipped with two stiffeners under the base plate of the motor, wherein one stiffener extends to the underlying filter surface which is designed to separate the antechamber of filter to avoid generating eddy; (3) Internal structure of EFU samples are relatively simple, 44#E is equipped with 44% open hole ratio of flow equalization wing plate (D=3. 5mm) and the ratio of CS#E is 22% which equipped with flow equalization planar plate (D=3. 5mm). Flow equalization plate help to enhance the uniformity of the outlet frontal velocity and reduce turbulence intensity of frontal velocity[5].

As shown in Table2, velocity profile of center region of 42#F and 44#F are relatively smooth, after flowing through the vane and bypassing the motor base plate then the airflow reach the bottom

Table 2. Outlet forms and Velocity profiles of FFUs& EFUs

Sample NO.	Outlet form	Velocity profile
42#F		
42#E		
CS#F		
44#F		
44#E		

of the motor, while the antechamber of FFU samples are sufficiently high, so the airflow mixture is relatively uniform at the central region. Regarding 42#E and CS#E, the lowest frontal velocity appear in the center region of the outlet plane for which the antechamber of EFU is small gap where the airflow mixture is nonuniform. Because 44#E is equipped with wing plate which expand the area of the narrow gap between filter and motor base plate, lowest velocity position of airflow migrate and appear beneath both sides of baffles where velocity gradient is also high.

CONCLUSION

(1) As ultra-thin products of FFU, thickness of EFU limits the internal structure design and leads to a difficult optimization of internal flow field, uniformity of central-regional velocity profile of EFU is worse than FFU.
(2) Experimental results show that even from the same manufacture, air velocity uniformity of each EFU sample is a great difference. Internal design has a enormous effect on uniformity of EFU product, in particular the common modulus of 44#E has a great potential optimization. Overall, effect by internal structure is greater than modulus size.

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