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Airflow Turbulence in a Unidirectional Cleanroom

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ABSTRACT

The characteristics of airflow turbulence in unidirectional cleanroom are described in this paper. Firstly, the airflow turbulence distribution is measured in a cleanbooth with a hot-wire anemometer. Through the analysis of turbulence levels, the shape of pleated HEPA filter is found out to be an important factor of eddy generation in airflow. Secondly, turbulence distribution behind HEPA filter is measured in detail. It concludes that the shear stress, caused by the airflow difference between pleated concave and convex of HEPA filter, makes eddy generation in airflow behind HEPA filter.

KEYWORDS Airflow Turbulence, Cleanroom, HEPA Filter

INTRODUCTION

It is evident that the airflow turbulence contributes significantly to particle transfer and thus to surface contamination in cleanrooms. The characteristics of airflow turbulence is necessary to predict particle behavior. It is wellknown that the airflow in cleanroom, even in unidirectional cleanroom, is turbulent. A large number of studies have been made on airflow in cleanroom; however, most of them dealt with the fully developed airflow, and little is known about transition stage of turbulence. In this paper, the mechanism of turbulence generation is discussed through measurment in a cleanbooth and behind HEPA filter.

ANALYSIS

In this study, analysises of turbulence level and power spectrum are carried out. Each index is explained as follows.

The air velocity at any time is given by equation (1).

$$u(t) = \overline{u} + u'(t) \qquad (1)$$

where, $\overline{u}$: Mean air velocity
$u'(t)$: Variation for $\overline{u}$

Turbulence level, TL, is defined by equation (2).

$$TL = \sqrt{\overline{u'(t)^2}} \ / \ u \tag{2}$$

Fourier transform of u(t) is given by equation (3).

$$X(f) = \int_{-\infty}^{+\infty} u(t) \exp(-i2\pi ft)\, dt \tag{3}$$

Power spectrum of air velocity is given by equation (4).

$$P(f) = \lim_{T\to\infty} |X(f)|^2 \ / \ T \tag{4}$$

Figure 1 shows an example of power spectrum with an approximate expression in the part of high frequency. The inverse of the slope, $1/\alpha$, indicates a dissipation rate.

$$\log P(f) = \log P_0 - \alpha f \tag{5}$$

OUTLINE OF MEASUREMENT

The airflow turbulence was measured at various points in a section of a cleanbooth with a hot-wire anemometer. **Figure** 2 shows the diagram of the cleanbooth and measuring points. The air velocity of point c (830 mm under HEPA filter) was defined as the standard air velocity in the cleanbooth. The airflow velocity in each point was measured for 32 seconds at 0.0025 seconds intervals. The data of the anemometer were transmitted to a personal computer system through an A/D converter, and were analized.

In order to investigate the airflow behind HEPA filter, the measuring system shown in **Figure** 3 was prepared. The air duct was made of acrylic resin with electrostatic shielding. Both vertical and horizontal component of air velocity were measured.

Figure 4 shows a typical structure of pleated air filter and air velocity distribution behind pleated filter. In the present study, 6 types of fiter shown in **Table** 1 were prepared to investigate the effects of filter form on airflow turbulence.

RESULTS AND DISCUSSION

Figure 5 shows the distributions of the mean air velocity and the turbulence level when the standard air velocity is 30 cm/s. There are large differences of them among the measuring points near HEPA filter. Turbulence levels behind the center of the filter are small.

Figure 6 shows the relation between $1/\alpha$ and the distance from the filter to measuring point. The values except those in line E get peaks near the filter, which means that the eddies are generated near the filter and are dissipated gradually. **Figure** 7 shows examples of the power spectrum.

Figure 8 shows the effects of standard air velocity on dissipation rate. The faster the airflow becomes, the larger the disspation rate becomes. This tendency is remarkable near the filter.

It is considered that the structure of pleated HEPA filter is an important factor of eddy generation and that eddies are generated near the filter because of shear stress as a result of difference between airflow from pleated concave and one from pleated convex.

Figure 9 shows the horizontal distributions of mean air velocity and turbulence. The airflow turbulence is large at the boundary between pleated concave and pleated convex at 4 cm below HEPA filter, and it is also large behind the pleated convex at 7 cm. It is considered that the eddies are generated near the boundary by a shear stress and are moved downward by airflow behind pleated convex which is faster than the one behind pleated concave.

Figure 10 shows the vertical distributions. As for type 1, standard HEPA filter, the mean air velocity behind pleated convex is more than ten times as large as the one behind pleated concave at 1 cm below the filter. The difference of them decreases gradually according as the distance from the filter. The turbulence gets a peak at about 10 cm below the filter. Type 2 and type 3 are similar to type 1. Type 4, mini-pleat filter without separator, shows little differnces in air velocity between pleated concave and pleated convex. The peak of turbulence occurs close to HEPA filter. As shown in type 5, airflow keeps stability by using coarse particulate air filter under HEPA filter.

CONCLUSIONS

1) Both turbulence level and dissipation rate are large near the filter. The dissipation rate becomes larger when airflow becomes faster.

2) Eddies are generated near the filter by a shear stress as a result of difference between airflow behind pleated concave and the one behind pleated convex and are moved downward by airflow behind pleated convex.

3) The use of a coarse particulate air filter under HEPA filter contributes to a reduction of airflow turbulence.

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Table 1: Investigated filters

	Filter size (mm)	Pleat span (mm)
type 1	HEPA 610×610×290(d)	D= 9.4
type 2	HEPA 610×610×150(d)	D= 9.4
type 3	HEPA 610×610×290(d)	D=17.5
type 4	HEPA 610×610× 65(d)	D= 3.75
type 5	(type 1)+Coarse particulate air filter	
type 6	(type 2)+Coarse particulate air filter	

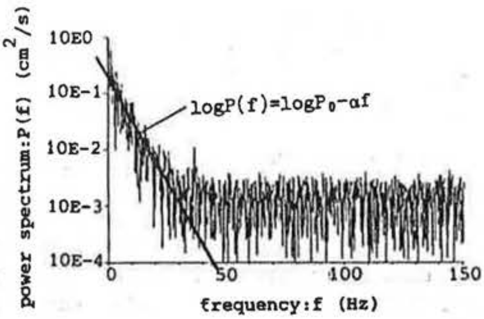

Figure 1: Approximation of dissipation rate

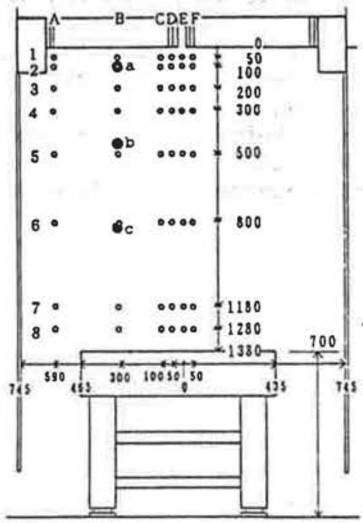

Figure 2: Measuring points in the section of the cleanbooth

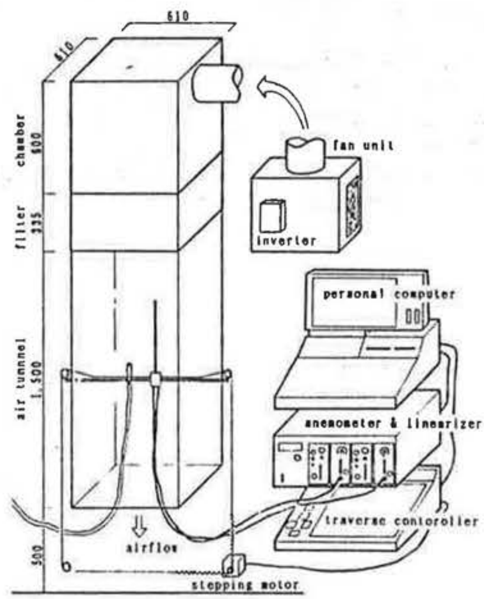

Figure 3: Measuring system for airflow turbulence behind HEPA filter

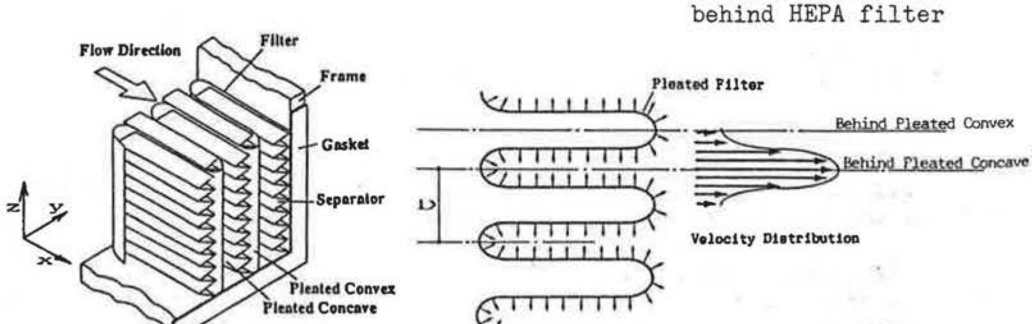

Figure 4: Typical structure of pleated air filter and air velocity distribution behind the filter

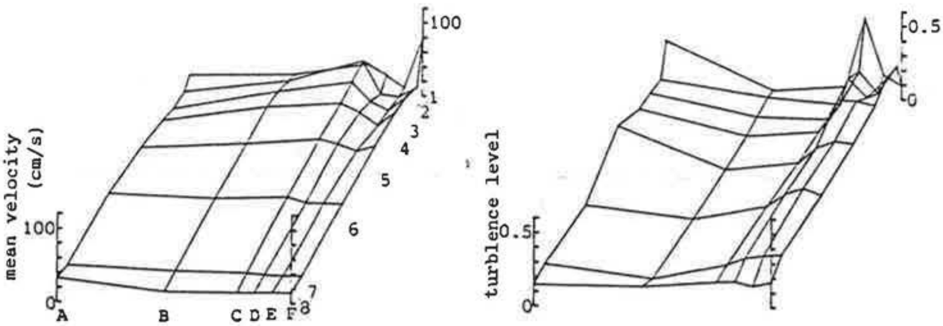

Figure 5: Distribution of mean air velocity and turbulence level

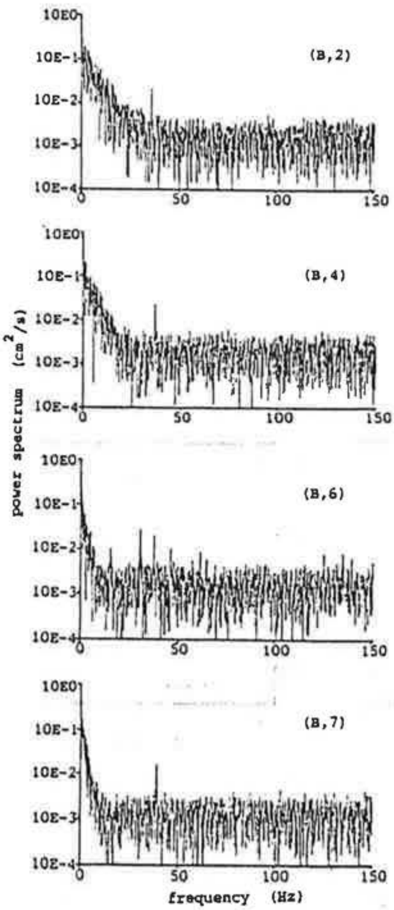

Figure 7: Power spectrum of air velocity in line B

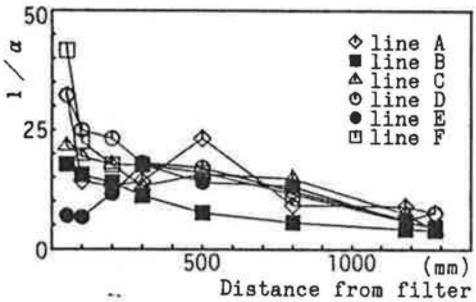

Figure 6: Relation between $1/\alpha$ and distance from filter to measuring point

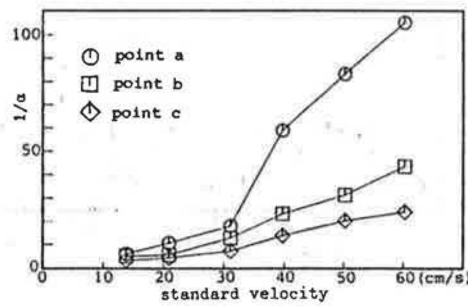

Figure 8: Relation between $1/\alpha$ and standard air velocity