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Noise in Cleanrooms Served by Fan-Filter Units: Design Considerations

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ABSTRACT

This paper is concerned with noise conditions in cleanrooms served by fan-filter units (FFUs), primarily of higher order clean class (ISO Class 1 through 5), although the concepts discussed also apply to rooms with higher particle counts (ISO Class 6 and higher). The need for frequent air changes to achieve the cleanliness goal is often the source of elevated noise levels from the HVAC systems. On the other hand, cleanrooms are often used in research and manufacturing environments that contain noise sensitive personnel and equipment. This paper illustrates typical design challenges in cleanrooms served by FFUs, either in the form of room boundary fan elements or "mini-environments" attached directly to sensitive the process and research equipment. FFU noise data formats, typical spectra, and noise mitigation options are discussed.

Key words: cleanroom, acoustics, noise control, criteria, fan-filter units, FFU

INTRODUCTION AND DEFINITIONS

Fan-filter units (FFUs) provide a relatively simple means of delivering filtered air to environments requiring high degrees of cleanliness.[1] They are autonomous units usually consisting of a small plug-type centrifugal fan (often variable in speed, which is controlled at the unit or remotely) and a high-efficiency particulate air (HEPA) or ultra low penetration air (ULPA) filter at the discharge, typically 1.2m x 0.6m or 1.2m x 1.2m in area. Cleanroom ceiling grids are fitted out with FFUs in varying density depending primarily on the clean class required. FFUs rarely if ever provide capacity for temperature control; instead in cleanroom recirculation systems using FFUs temperature control is provided by external coils or by make-up air units containing temperature controlling elements.

FFUs provide an alternate to other types of recirculating air fans often used in cleanroom systems, such as larger plug or centrifugal fan units or vaneaxial fan systems. Architects and mechanical engineers may prefer the use of one of these types of systems based on energy efficiency, redundancy,[2] simplicity of installation or retrofit, cost, etc. From an acoustical standpoint, several important design considerations are implied with the use of FFUs in cleanroom environments.

[1] The cleanliness Class of a cleanroom is defined by the number of allowable particles of specific size per unit volume [1].
[2] Typically, many FFUs are required (with a typical flow rate of 700 to 1,300 m^3/h each) to provide the same flow rate as the other systems mentioned (often specified to provide flow rates in the range of 50,000 to 200,000 m^3/h each). Failure of one motor in the former case will usually be less catastrophic than in the latter case.

Variation in noise among various makes and models of FFUs

The noise levels produced by FFUs of various makes and models can vary significantly, even when delivering the same flow rate against the same external static pressure. To demonstrate this, an experiment was setup wherein several different FFUs were installed in succession in the ceiling space of a typical small clean laboratory environment. Since the return air path and HEPA filter installed on each was similar, it can be assumed that the external static pressure drop for each was similar. The face velocity was verified to be 0.37 m/s in each case, corresponding to a flow rate of 959 m^3/h for the 1.2m x 0.6m filters. Figure 1 compares the sound power of four FFUs installed in this configuration, determined using sound intensity techniques carried out according to ISO guidelines [2][3] with calibrated engineering grade (ANSI Type 1) instrumentation [3]. The outlet sound power levels of the four FFUs are significantly different, varying as much as 20 dB in some frequency bands. As will be discussed below, this also resulted in correspondingly different sound pressure levels in the test laboratory.

A second experiment examined the variation in noise level due to various configurations of an FFU from one manufacturer. This is shown in Figure 2 (outlet noise)[4] and Figure 3 (inlet noise). The differences include fan wheel type variations (Models 1 and 2) and enclosure design variations (Model 3 has a different enclosure from Models 1 and 2). Although the variation in noise levels is not as dramatic as from manufacturer to manufacturer, there are still significant differences in sound power in most frequency bands on the outlet side, and at 125 and 500 Hz on the inlet side.

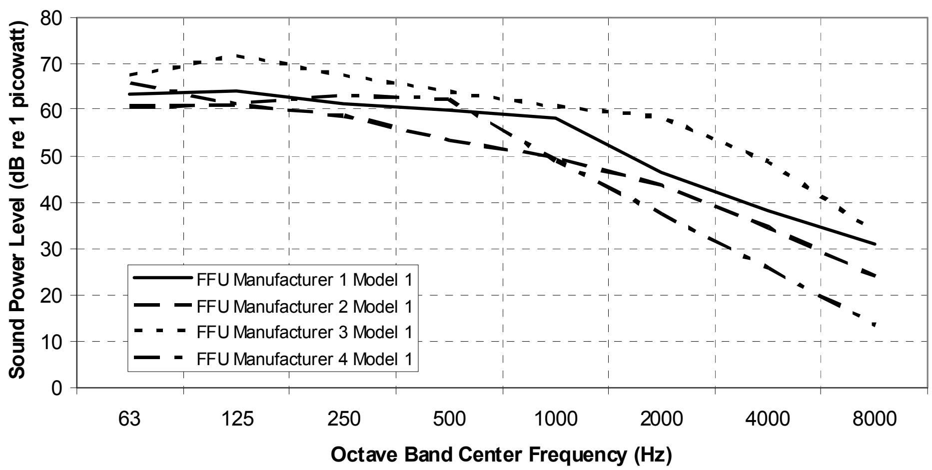

Figure 1: Outlet sound power levels for four FFUs of different manufacturers measured under uniform flow rate, static pressure, and other environmental conditions

[3] Numbers in square brackets indicate references, at the end of the paper.
[4] In one of the spectra shown in Figure 2, data are not provided above 2000 Hz since they were not distinguishable above the background ambient noise level.

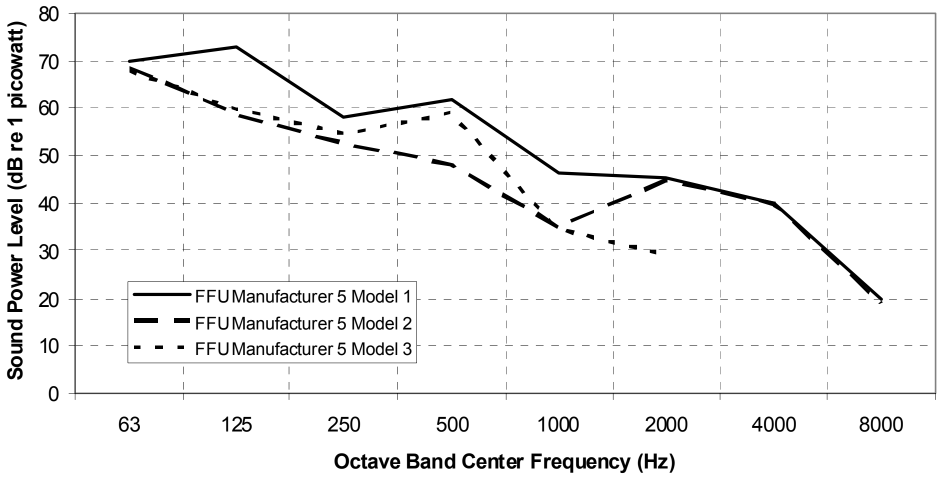

Figure 2: Outlet sound power levels for three models of FFUs by the same manufacturer measured under uniform flow rate, static pressure, and other environmental conditions

FFU noise data formats and test set-ups

In the design stage of a cleanroom construction or retrofit project, in order to predict the noise levels in a lab or cleanroom to be served by FFUs, it is necessary to have reliable sound data from the FFU manufacturers. For the data to be considered reliable, it must be determined by following internationally accepted data measurement and presentation standards. Ideally, data for the inlet and outlet of the FFU should be expressed as sound power levels with a minimum frequency resolution of octave bands. As the sound power is a function of the flow rate and total static pressure (TSP) seen by the unit, these quantities must also be reported with the acoustical test data.

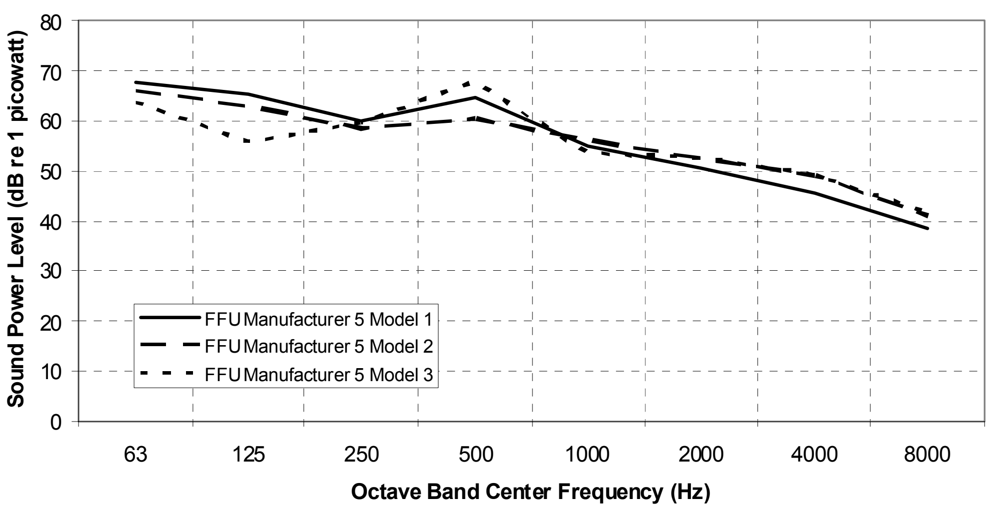

Figure 3: Inlet sound power levels for three models of FFUs by the same manufacturer measured under uniform flow rate, static pressure, and other environmental conditions

At the time of this writing, there does not appear to be any acoustic measurement and reporting standard specifically for FFUs (although there are standards for other air movement systems that could be adapted to FFUs). The result is that manufacturers rate their systems with a variety of indices, and usually other than in sound power levels, such as a sound pressure level with or without a statement of the measurement distance from the unit, or as the value of the standard criterion curve expected to be achieved in a room (e.g., NR, NC, etc.). These are often given without stating the TSP and other environmental conditions during the measurements.

It is acknowledged that it would be easier to allow the provision of octave band sound pressure levels determined at a specified distance from the FFU, since this is easier to measure. However, as this index is not an inherent quality of a source, but also includes environmental factors, it is not a reliable index for comparison of various sources, or prediction of the impact of these sources when introduced into an arbitrary environment that may differ significantly from the FFU manufacturer's lab. To demonstrate some of the complications associated with rating FFUs in units of sound pressure, Figure 4 shows the sound pressure level measured 1m below the same four FFUs represented in Figure 1, and under the same operating conditions.[5]

On first inspection the spectra shown in Figures 1 and 4 are very similar, perhaps indicating a relatively constant conversion factor from outlet sound power to pressure at 1m. However, in tabulation, it is seen that the conversion factors can vary significantly from unit to unit. See Table 1 for a summary of the data ranges. These variations may be due to differences in the relative ratio of inlet to outlet noise for the various units, error due background ambient noise contamination, sound field variations, and other factors.

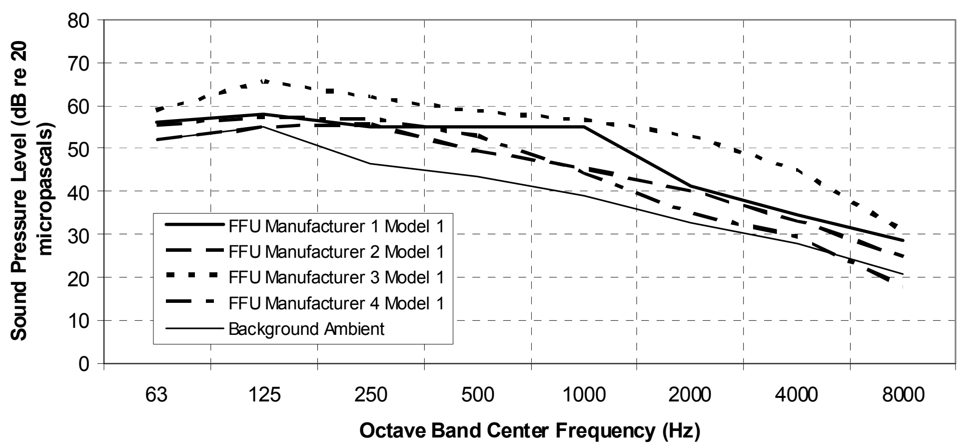

Figure 4: Sound pressure levels measured 1m from the outlet of the four FFUs shown in Figure 1

[5] These sound pressure level data have been corrected for contribution from the background ambient noise level, which is also shown in Figure 4.

Table 1: Outlet sound power to 1m sound pressure conversion factors (dB) versus octave band center frequency (Hz) for test data contained in Figures 1 and 4

	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
FFU Manufacturer 1 Model 1	-7.3	-6.0	-6.1	-4.8	-3.6	-5.1	-3.8	-2.4
FFU Manufacturer 2 Model 1	-8.5	-6.1	-3.1	-4.0	-4.1	-3.6	-1.2	0.6
FFU Manufacturer 3 Model 1	-8.6	-5.8	-5.6	-5.2	-4.2	-5.3	-4.0	-2.6
FFU Manufacturer 4 Model 1	-10.2	-3.9	-6.2	-9.2	-4.9	-2.4	3.7	4.4
Average and Data Range	-8.6 2.9	-5.5 2.2	-5.2 3.2	-5.8 5.2	-4.2 1.3	-4.1 2.9	-1.3 7.7	0 7.0

In any case, the power-to-pressure conversion factors given above are only valid for the test room in which they were measured. Other rooms will produce different factors depending on the contribution from the intake noise, room absorption, background ambient noise level, etc.

In addition to the fact that the FFU should be tested at the design operating point as mentioned, the factory test set-up should also duplicate the FFU support conditions and orientation of the final installation position, as these conditions may affect the sound radiating surfaces of the FFU, and internal and external vibration loading conditions.

In summary, it may be possible to develop a uniform sound pressure testing methodology for FFUs, but the data provided show that, until a method to reduce unit to unit test error is developed, properly measured sound power data are likely to be more reliable.

NOISE CONTROL

Standard means

For other types of cleanroom and laboratory recirculation air handling systems, noise control can sometimes be achieved by specification of the required sound power levels or by use of external silencers. In the former case, it is the responsibility of the manufacturer to modify the fan unit, if necessary, to meet the specified inlet and outlet sound power levels, with the use of internal lining, internal silencers, convolutions, fan selection, etc. This is more practical when the air handler is custom built for the application. In the case of the FFU, these are typically not custom built, and often hundreds of a manufacturer's standard unit are installed in a ceiling space. In addition, the small cabinet size provides fewer options for internal noise control, although most manufacturers have taken steps in this regard. The use of an external silencer is usually not feasible for FFU installations as their integral outlet filters form the ceiling of the cleanroom.[6]

[6] Technically, use of an acoustical louver system under the FFU may be possible, but the sound absorptive fill would probably have to be encapsulated (e.g., enclosed in a Mylar® or Tedlar® film) to avoid outgassing and particle shedding. Also, application of an inlet silencer is technically possible, if needed. These noise control methods might become cumbersome and expensive if it is necessary to provide them for hundreds of units.

Noise control by fan speed

A more practical means of reducing FFU noise is to reduce the operating speed of the fans. To illustrate the benefit, Figure 5 compares the outlet sound power of an FFU operating at two face velocities, 0.36 m/s and 0.30 m/s (933 m^3/h and 778 m^3/h flow rate). In this case, for a 17% reduction in face velocity and flow rate, there is a 50% reduction in noise level (3 dB) at 125 Hz, and better reductions in octave band noise levels at higher frequencies.

This benefit, and other effects, is also demonstrated in Figure 6. This figure shows the narrowband[7] sound pressure measured at the intake of an FFU while it is operated at various speeds. The broadband sound pressure decreases with fan speed, as would be expected. (The residual background noise shown in Figure 6, when the test FFU is powered off, is due to the many other FFUs operating nearby.)

These concepts point to a possible means of noise control when the ceiling FFU coverage is not 100%, as is very often the case. In this case, the ceiling coverage density can be increased using FFUs operating at slower speeds, in order to achieve the same total flow rate but at reduced noise levels. That is, although there is an increase in noise associated with the addition of more FFUs, there is a proportionally greater decrease in noise associated with the corresponding reduction in fan speed of the FFUs. Other benefits include a corresponding increase in room sound absorption (in fact, it is often the case that the HEPA filters associated with the FFUs constitute a major portion of the absorptive material in a cleanroom, so the effect can be significant), and the possibility of increased energy efficiency. A detriment is a higher capital cost for the initial construction.

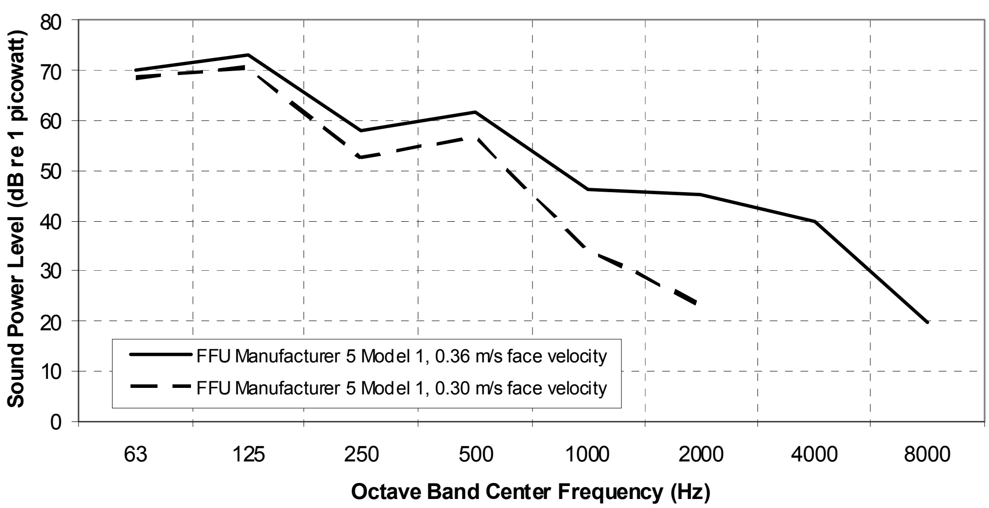

Figure 5: Effect of fan speed on outlet sound power level

[7] These data have a resolution bandwidth of 1.6 Hz and were measured using a Hanning windowing function, giving an effective bandwidth of 2.3 Hz.

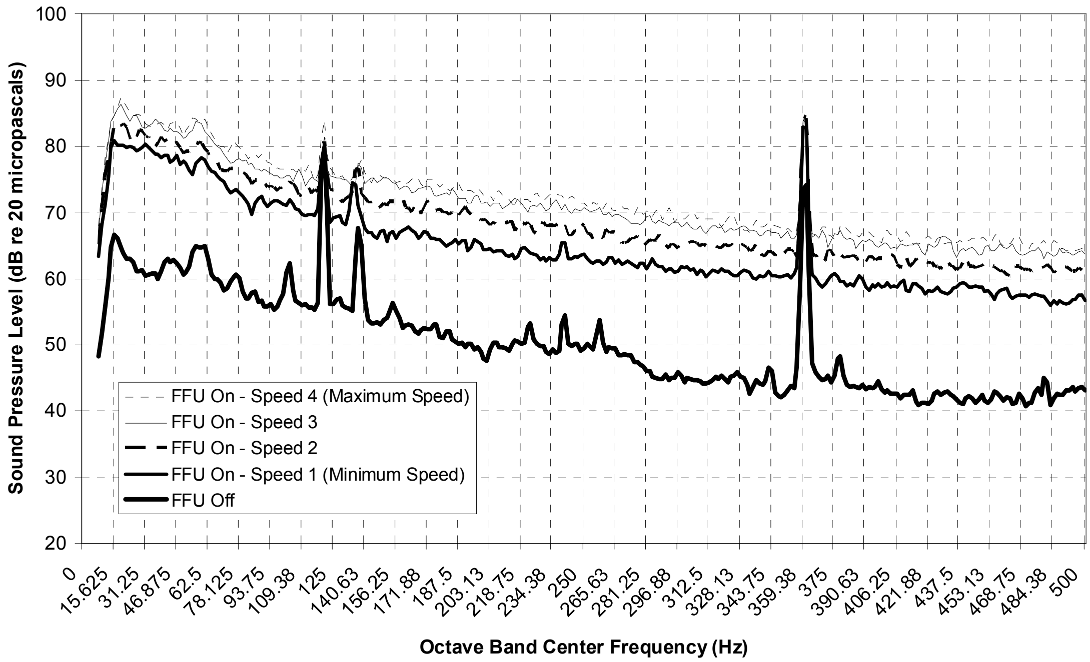

Figure 6: Effect of fan speed on inlet sound pressure level (effective bandwidth = 2.3 Hz)

Noise control by reduced clean class

Many cleanrooms have been built lately with the concept of using a lower clean class in the general clean room area (say, ISO Class 5 or 6), with cleaner conditions provided locally at the process or research tools (say, ISO Class 3 or 4) using *minienvironments*. Minienvironments are essentially local environmental chambers enclosing the tool and typically served by built-in FFUs. While this scheme has the benefit of potentially providing much lower noise levels in the empty cleanroom due to the cleanroom FFUs, the primary noise problem is essentially transferred to the tool minienvironment FFUs, over which the building owner may have less control as this is associated with an integrated and individual process or research system. In these cases, we have measured increases in noise levels from the standard criterion curve NR-50 before tool operation due to the cleanroom FFUs alone, to nearly NR-70 with the tools (and their minienvironments) in operation. To prevent this, the development of purchase specifications for noise sources associated with the tools would be beneficial. The use of intake silencers for the minienvironment FFUs could also be considered.

Other elements of FFU noise

Figure 6 shows other phenomena that may be important in the acoustical design of rooms served by FFUs. Three tones appear in the spectra, at 120 Hz, near 136 Hz, and at 360 Hz. The tones at 120 and 360 Hz are associated with the power supply for the FFU motor in this case. This type of signal is not present with all makes of FFUs, but is particularly prominent in this case and was the cause of complaints from workers in the lab. The amplitude of the tone varies 3 to 4 dB throughout the speed range, compared with a variation of 10 dB in broadband noise. Thus, the tones became even more noticeable at lower operating speeds. This problem was solved by using a different power supply.

Another more subtle tone varies in amplitude (78 to 74 dB) and frequency (139 to 134 Hz) in proportion to the fan speed. This is the *blade passage frequency* of the fan, which is a function of the fan speed and number of blades in the fan wheel. This is a more normal feature of fan noise, and methods of reducing its impact are well discussed in the literature.

Conclusions

Fan-filter units provide a practical means of particulate control in cleanrooms, both in service to the room or directly to research equipment in the form of minienvironments. However, they are a significant source of noise, and their compactness comes with significant acoustical design challenges. With good definition of the sound power of the FFUs under various operating conditions, it is possible to select appropriate units and minimize the noise impact by adjustment of the FFU density and operating speed.

References

[1] "Cleanrooms and associated controlled environments, Part 1: Classification of air cleanliness" International Organization for Standardization *Standard* ISO 14644-1

[2] "Acoustics, Determination of sound power levels of noise sources using sound intensity, Part 2: Measurement by scanning" International Organization for Standardization *Standard* ISO 9614-2

[3] "Specification for sound level meters" American National Standards Institute *Standard* ANSI S1.4