Baltimore, Maryland
NOISE-CON 2010
2010 April 19-21

Active noise control of multiple cooling fans

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Multiple fans are used to cool some types of electronic equipment. Fan arrays are louder than single fans and closely space blade passage frequencies create an annoying beat frequency. A sound power reduction technique using active noise control is implemented to control the blade passage frequencies and the second harmonics of a two fan array. The control system will use near field error sensors and control sources. The two blade passage frequencies and second harmonics had a sound power attenuation of 14.9, 10.2, 7.7 and 5.6 dB respectively. The reduction of the tonal noise masked the beat frequency in the broadband.

1 INTRODUCTION

Fan arrays are used to cool electronics. Multiple fans improve cooling but increase noise levels. Single fans produce tonal noise at the blade passage frequency (BPF) and the harmonics that are related to the rotation of the fan. Due to differences in manufacturing, identical model fans will generally rotate at slightly different speeds when the same voltage is applied; therefore, when multiple fans are used, there are two blade passage frequencies. Because the BPFs are close together, they create an annoying beat frequency. Elimination of the beating frequency has been attempted by various researchers[1,2]. Additionally, the active control of the tonal noise content of signal axial cooling has been implemented using various configurations[3-8].

A sound power reduction technique using active noise control implement by Gee and Sommerfeldt[3] on a single axial cooling fan will be applied to a two fan array in this paper. Gee and Sommerfeldt modeled the fan as a point source and minimized the far field sound power using Nelson's method. Nelson[9] showed that the sound power of a simple source could be reduced globally using near field control sources. The expression for the total sound power of the primary and secondary sources can be differentiated and minimized by changing the control source strength. By finding the optimal control source strengths, Gee calculated the near field pressure field relative to the primary field. He then placed the error sensors on the nulls in the near field. By doing so, the control system is forced to minimize the far field sound power. The benefit of this approach is that the sensors and control sources are located around the fan.

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Active noise control for multiple fans, in addition to quieting the fans, can mask the beat frequency in the broadband noise. The objective of this paper is to apply free field active noise control to a two fan array by using near field error sensors and control sources.

2 SOURCE MODELING

2.1 Multiple Fan Noise

Fan arrays have multiple single axial cooling fans that act as independent noise sources. A single axial cooling fan generates tonal noise associated with the BPF and its harmonics, which are determined by the rotation rate of the fan and the number of blades. Multiple fan systems are often implemented with identical fans arranged side by side. Despite the same model fan being used, manufacturing differences cause the fans to rotate at slightly different speeds, creating two BPFs. Since this research is aimed at controlling the tonal noise, each fan can then be modeled individually as independent radiators. Gee showed that the noise from a chassis-mounted fan could be actively controlled by modeling the fan as a monopole at low frequencies[3]. In this research, each fan will be modeled as a monopole radiating into free space at the BPF and the first harmonic.

2.2 Control Source Configuration

Nelson showed an inverse relationship between the value for *kd* and the amount of global control that can be achieved, where *k* is the wave number and *d* is the distance from the control source to the primary source[8]. In order to have the smallest *kd* possible, the control sources will be placed as close to the fans as practically reasonable. Also, Gee showed that for his configuration, four control sources surrounding the primary source and four error sensors overall proved to have the greatest far field sound power reductions. However, with the limited footprint available, four control sources could not be used to surround each fan hole. Instead three control sources were placed surrounding each fan for a total of six control sources, as can be seen in Fig. 1. The source arrangement is similar to the configuration Gee and Sommerfeldt implemented[4].

2.3 Error Sensor Placement

The error sensor placement is determined according to the near field pressure generated using the optimal secondary source strengths. Figure 2 shows the theoretical near field pressure relative to the primary pressure field at 600 Hz. The figure shows a pressure minimum surrounding the primary sources and going in front of the control sources. The controlled field will have a maximum pressure reduction along this contour, which represents desired error sensor locations. Driving the pressure to zero along the null will result in a control solution that reduces the sound power radiated from the fan. The theoretical sound power attenuation is 29.9 dB.

3 EXPERIMENTAL SETUP

Two 60 mm fans were exhaust mounted on a computer box with dimensions of 46 x 42x 22 cm. The fans were spaced 6.5cm apart, center to center. The secondary sources were placed according to Fig.1 and the complete set up is shown in Fig. 3. Feed-forward control requires a reference signal that is correlated to the noise source. Since these fans do not have a tachometer output signal available, the reference signal was taken from an emitter detector pair mounted on the fan that gives a pulse each time a fan blade passes. This method has been used in previous studies[4]. The reference signals from each fan were mixed and used in the filtered x algorithm. The control sources are HiVi 1" shielded tweeter loudspeakers and the error microphones are 6mm Hosiden electret microphones. The error sensors were placed on the theoretical pressure nulls. Figure 3 shows the experimental set up of the two fan array. Anti-aliasing filters were implemented with a cutoff frequency of 1800 Hz using Krohn-Hite 3384 filters.

The fan array was placed in an anechoic chamber to measure the sound power reduction of the tonal frequencies. The measurement is obtained using a semicircular array with a radius of 1.7 m and the 13 microphones equally placed along the semicircle. The boom is then rotated to give measurements over a complete hemisphere. A picture of the measurement array can be seen in Fig. 4. The fan array was placed directly under the center microphone and the array was rotated about the center microphone at 15 degree increments to create a 360 degree scan. The microphones are GRAS 1/2" type I microphones. At each microphone location, the auto spectrum was calculated with 15 averages with a frequency resolution of 6.1 Hz. The sound power attenuation was calculated and the total reduction of the blade passage frequency and the first harmonic were found by integrating over a 12 bandwidth for each frequency. Five measurements were taken with control on and off for each fan operating individually and both fans operating together.

4 RESULTS AND DISCUSSION

The sound power spectrum was calculated for control on and off for each measurement. The sound power was calculated with the same method as Monson et al.[11] Monson implemented an area weighting function to calculated the radiated sound power from equal angle positioned microphones on a semicircular measurement array. The blade passage and 2nd harmonic reduction were calculated with a 12 Hz bandwidth centered at each frequency of interest.

Figures 6-8 show the results for control on and off sound power spectrum for each fan operating individually and both running together. Figure 6 has the sound power of the first fan in the array operation by itself. The figure shows the BPF at 690 Hz and 1380 Hz for the 2nd harmonic. The control system was able to attenuate the radiated sound power of the first fan's BPF by 16.0 dB and 2nd harmonic by 10.2 dB. Figure 7 shows the sound power spectrum of the second fan in operation by itself with the BPF at 708 Hz and the 2nd harmonic at 1416 Hz. With active noise control, the BPF and 2nd harmonic were attenuated 16.5 dB and 8.9 dB. Figure 8 shows the sound power spectrum of both fans in the array in operation with the two BPFs at 683 Hz and 701 Hz. The BPF were attenuated by 14.9 and 10.2 dB, respectively and the 2nd harmonics at 1366 Hz and 1402 Hz attenuated by 7.7 dB and 5.6 dB. With both fans in operation, one fan had greater reduction than the other; However, looking at the spectrum, each fan's BPF was reduced to the same radiated sound power level.

Tables 1 and 2 have the individual sound power reduction of each trial of the experiment. Table 1 has the results for individual fans in operation and Table 2 is when both fans are in operation. Tables 1 and 2 show the variance in repeated experimental runs is very small. The largest standard deviation for repeated experimental runs is 0.3 dB. The small standard deviation means that the control system converged to nearly the same solution during each experiment. In comparing Table 1 and Table 2, the achievable attenuation decreases when both fans were in operation. Despite having lower attenuation values for the BPFs and 2nd harmonics than the individual runs, Figs. 6-8 shows that the tones are driven closer to the broadband noise for the fan array than the each fan in operation by itself. Suggesting, the broadband noise will mask the remaining tonal noise content for the fan array better than the individual fan control. The masked tonal noise content of the two fan array will also make the beat frequency less noticeable.

5 CONCULSION

The fan array was controlled using near field error sensors and control sources. Each fan in the two fan array was modeled as a monopole operating at a slightly different frequency. The sound power of the BPF of each fan in the array was attenuated by 14.9 and 10.2 dB with the second harmonic attenuated by 7.7 and 5.6 dB, respectively. The attenuation of the BPFs masked the beat frequency in the broadband noise, making it less noticeable.

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Table 1 - Sound power reductions (dB) of single fan tests.

	Fan 1		Fan 2	
runs	BPF	2x BPF	BPF	2x BPF
1	15.9	9.9	16.4	8.4
2	16.0	10.2	16.5	9.3
3	16.0	10.5	16.8	8.7
4	16.0	10.1	16.4	8.9
5	16.1	10.2	16.6	9.4
Average	16.0	10.2	16.5	8.9

Table 2 - Sound power reductions (dB) both fans in operation

	Fan 1		Fan 2	
runs	BPF	2x BPF	BPF	2x BPF
1	14.6	7.8	10.2	5.3
2	14.6	7.4	9.8	5.3
3	14.3	7.3	10.5	5.7
4	14.4	8.1	10.3	5.9
5	14.7	7.8	10.0	6.0
Average	14.9	7.7	10.2	5.6

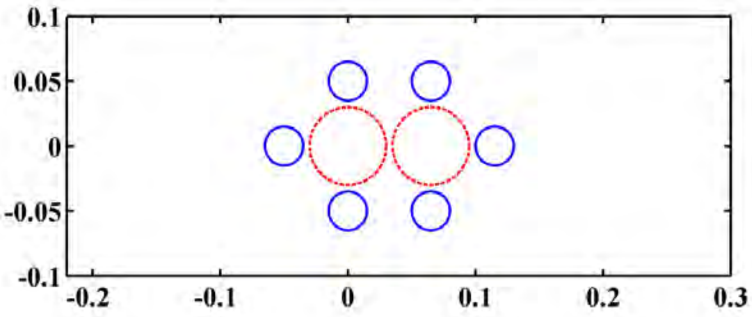

Fig. 1 - The control configuration for two primary sources (dashed lines) and 6 control sources (solid lines).

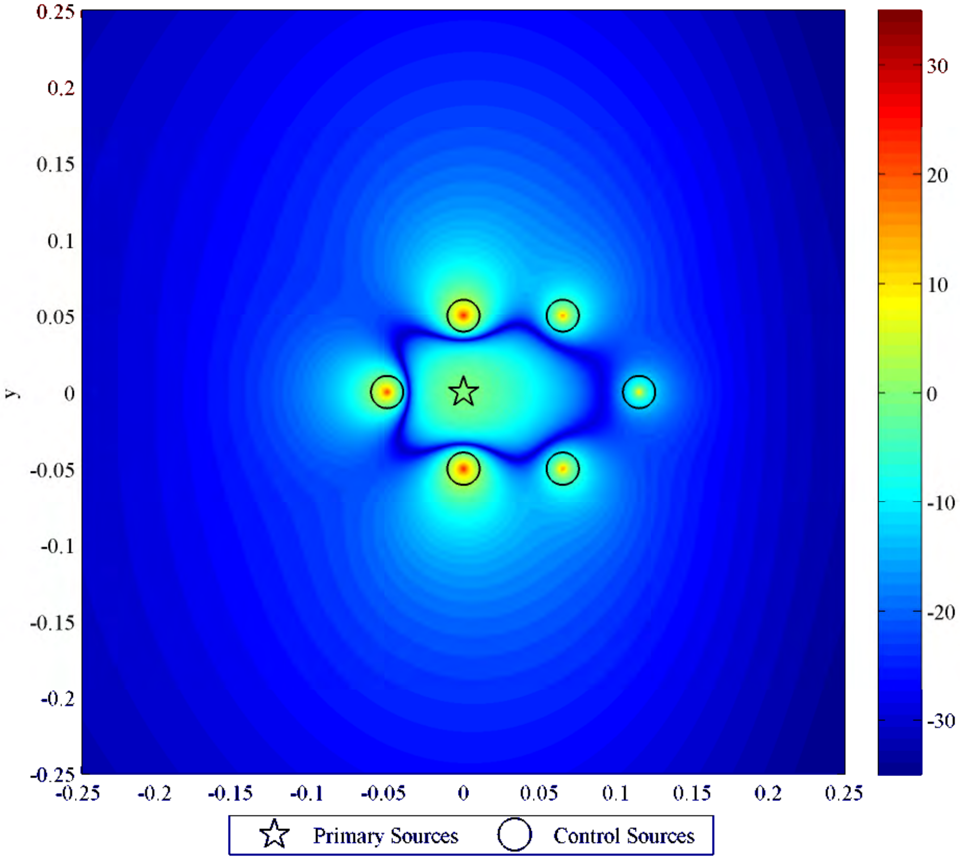

Fig. 2 – The control pressure field (dB) reference to the primary pressure field at 600 Hz. The minimum in pressure around the primary sources is the optimal locations for the error sensors.

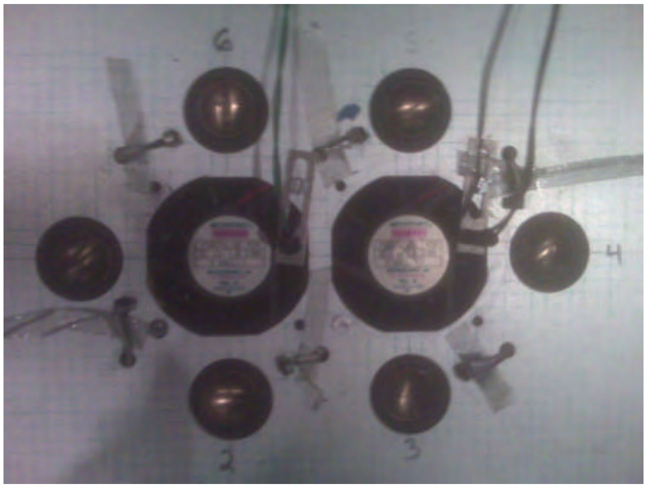

Fig. 3 - The experimental set up with 2 fans and 6 control sources surrounding.

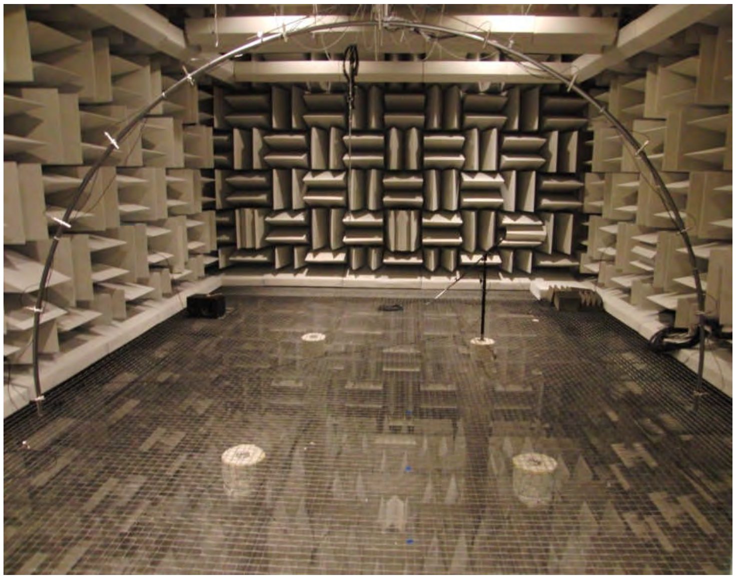

Fig. 4 – The anechoic chamber and semicircular measurement array.

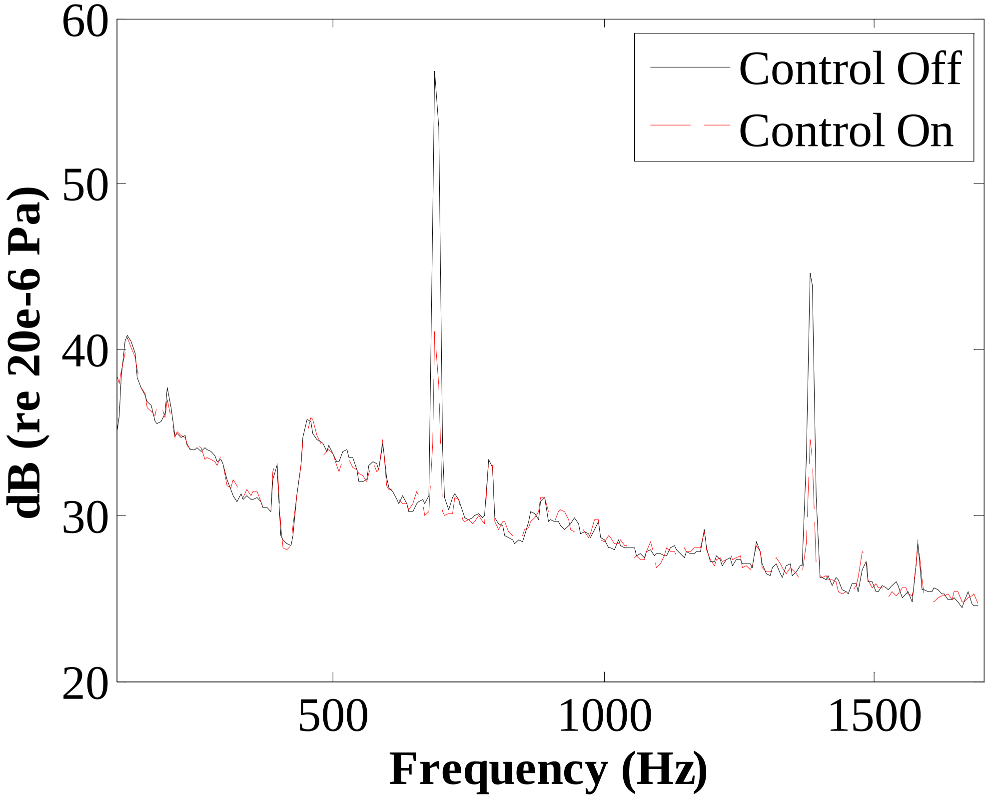

Fig. 5 - *The sound power with control on and control off of with the first fan in operation.*

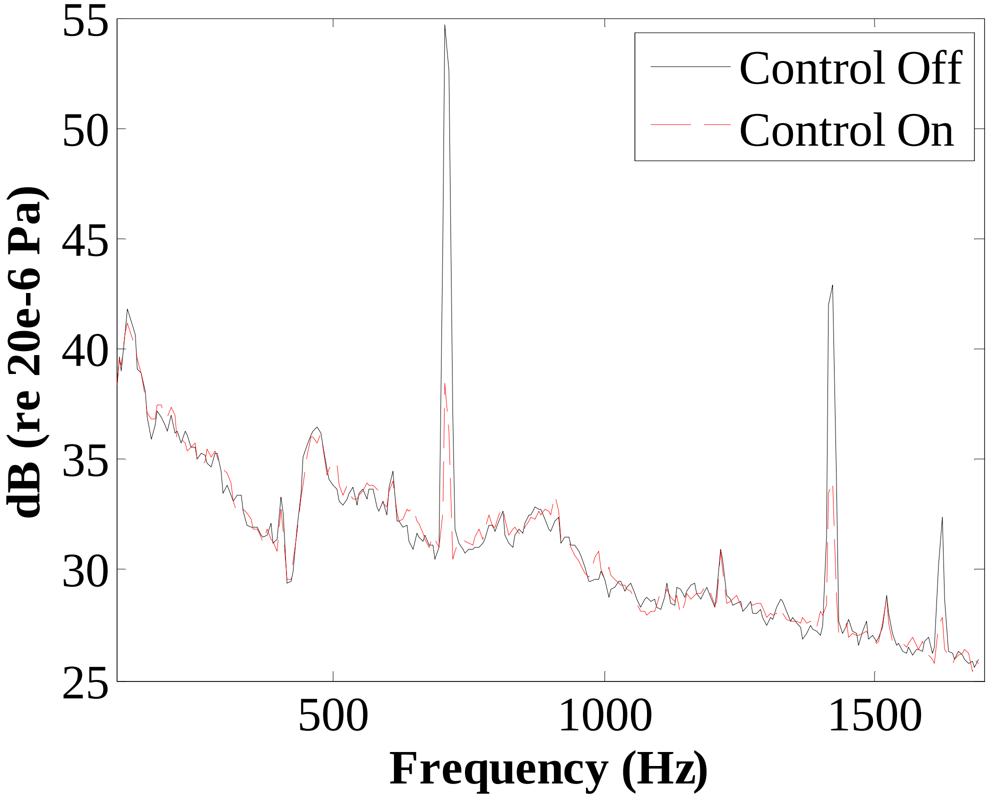

Fig. 6 - *The sound power with control on and control off of with the second fan in operation.*

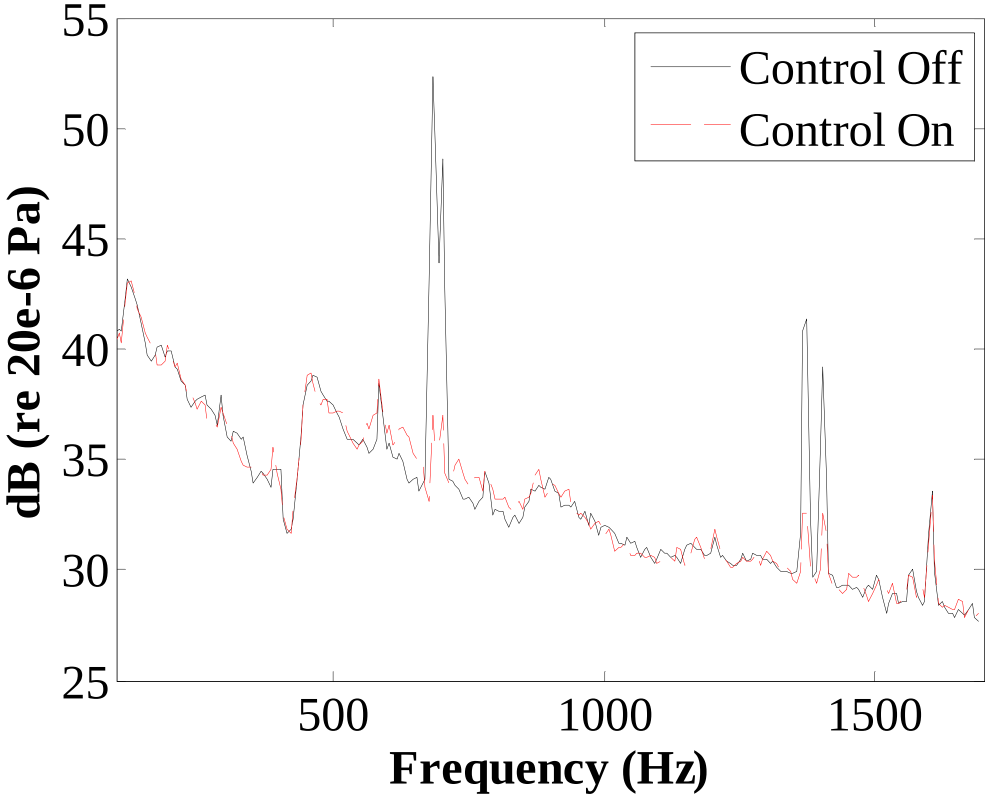

Fig. 7 - The sound power of a two fan array with control on and off.