CFD Analysis for Control Element Drive Mechanism Cooling Fan

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1. Introduction

The Control Element Drive Mechanism (CEDM) is cooled by the CEDM cooling fans. Each of the CEDM cooling fans shall be designed to provide enough cooling air to the CEDMs [1]. The fans are installed on the top of the Integrated Head Assembly (IHA) in the APR1400 nuclear power plants. When the fan is in operation, it shall not generate the sound level over 115 dB(A) for the APR1400 IHA. The sound level of the fan is normally verified by the sound level test at the shop. However, it has not been simulated using a computer program in the design process.

The design of the CEDM cooling fan for the APR1400 IHA includes a blade type passive back-draft damper. The blade type damper is respectively weak in strength compared to the butterfly type damper due to its size. So, the butterfly type damper is considered as one of the options in the CEDM cooling fan design for the improving IHA. In the current design of the CEDM cooling fan, the hot air after cooling the CEDMs and reactor vessel head nozzles is discharged in the vertical direction. As a result, the hot air may be stacked in the top region of the containment building. Therefore, it is likely that the required design temperature of the containment building is not met locally. So, the control of the damper angle may be necessary to decrease the local temperature of the containment building.

In this paper, the Computational Fluid Dynamics (CFD) analysis has been performed to estimate the sound level produced by, and the effects of the angle of the butterfly type damper applicable to the current CEDM cooling fan.

2. Methods and Results

2.1 Sound Level Analysis

The CEDM cooling fan of the APR1400 IHA is two (2) stage vane axial type having 10 blades for each rotor and 9 guide vanes. There are three (3) CEDM cooling fans installed on the IHA, and two (2) of them are active during the normal operation.

According to the APR1400 test results, the back ground sound level is identified as 70.6 dB(A), and the sound level produced by the motor of the CEDM cooling fan is about 80 dB(A). Besides, the CEDM cooling fan is installed on the spring type vibration isolator. So, it is reasonable to consider that the main source of the sound level produced by the CEDM cooling fan is its blades.

Some of the information for the blades, such as the cross section profile and installation angle, is manufacturer dependent. Herein the cross section profile was assumed as the NACA 4408 airfoil [2]. Then, the installation angle was determined by the comparison of the blade installation angle and flow rate of the cooling air. To check the flow rate against the blade installation angle, the quasi-static analysis has been performed by using the Moving Reference Frame (MRF) option in the ANSYS Fluent [3]. The k-ω SST turbulence model [4 & 5] was applied because the distance between the outmost region of the blade and fan casing is about 0.2 inch. The determined blade installation angle is 30° at the rotor, and 20° at the outmost region of the blade against the horizontal line. The angle of blade is smaller at the blade outer region comparing to the rotor location because the speed at the outer region is higher than the rotor location. The shape of the CEDM cooling fan model used in the CFD analysis is shown in Figure 1.

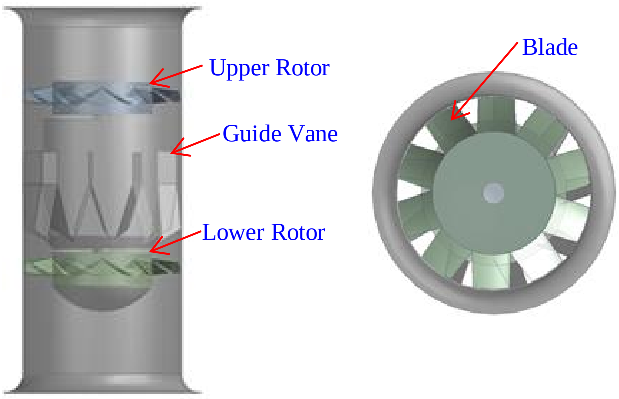


Fig. 1. CEDM Cooling Fan

The APR1400 CEDM cooling fan is required to provide the air flow rate of 44,000 ~ 48,400 CFM (ft^3/min). The test results showed the flow rate is about 44,000 CFM while the MRF analysis result showed that the flow rate of the CEDM cooling fan is 4.26% higher than the required minimum flow rate. However, the difference with respect to the flow rate is less than 5%. So, the MRF result is still meet the design requirement. Therefore, the transient analysis has been performed using the determined blade installation angle with the assumed blade profile. In the transient analysis, the Ffowcs Williams & Hawkings model [6] has been applied to calculate the sound pressure level. Then, the A-weighted sound pressure levels at each receiver location are combined for the octave band frequencies

[7]. The receiver locations are 1 meter away from the center of the fan at the outlet elevation with the angle of 0˚, 45˚, and 90˚ as shown in Figure 2.

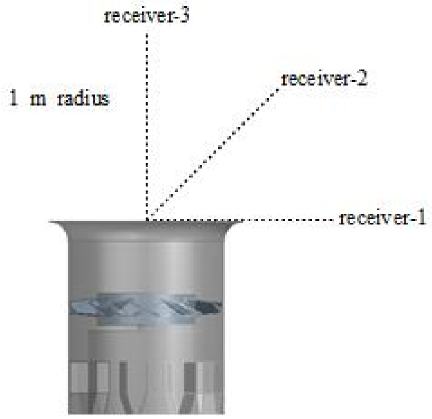
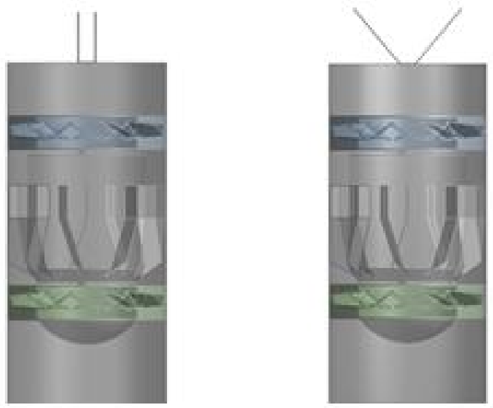


Fig. 2. Receiver Locations (1 ~ 3)

2.2 Damper Effect Analysis

The butterfly type damper has been applied to the improving IHA [8]. As applied to the sound level analysis, the k-ω SST turbulence model is applied to study the damper angle effects against the flow rate and differential pressure across the CEDM cooling fan. Only the quasi-static analysis with the MRF option has been performed for the economic reason. The analysis model has been changed to accommodate the butterfly damper.

The inlet and outlet bells were removed. The inlet bell was removed not to interfere with the fan support structure. And the outlet bell was also removed to apply the damper. It is possible to adopt those bells with the butterfly damper. But the bells for inlet and outlet with butterfly damper are not common. There are 5 models applied in this case study with respect to the damper angles of 0˚, 10˚, 20˚, 30˚, and 40. Only two (2) models with the damper angles of 0˚ and 40˚ are shown in Figure 3.



(a) Damper angel of 0˚ (b) Damper angel of 40˚

Fig. 3. Damper Effect Analysis Model

2.3 Sound Level Analysis Results

First, the quasi-static analysis result of the sound level analysis is checked to see the main source of the fan sound. The result of the acoustic power level indicated that the main source of the fan sound is the leading edge region of the fan blade as depicted in Figures 4 and 5.

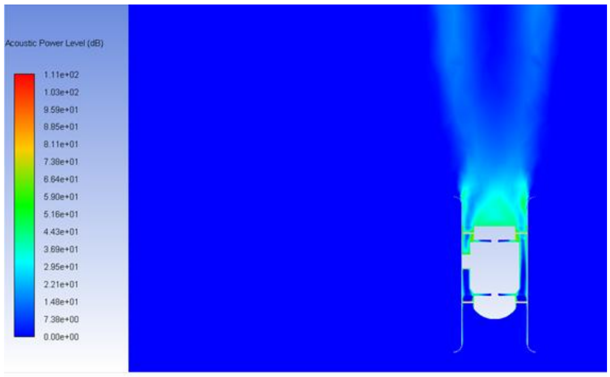


Fig. 4. Acoustic Power Level (dB) of the Fan

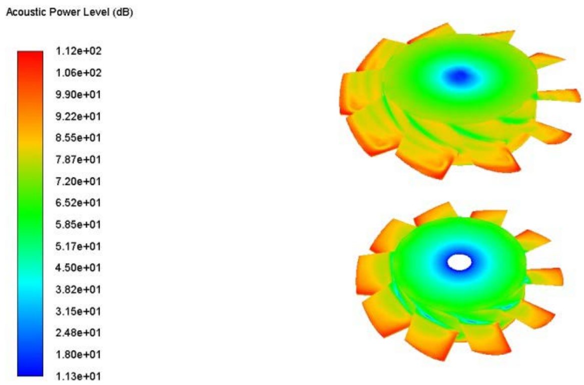
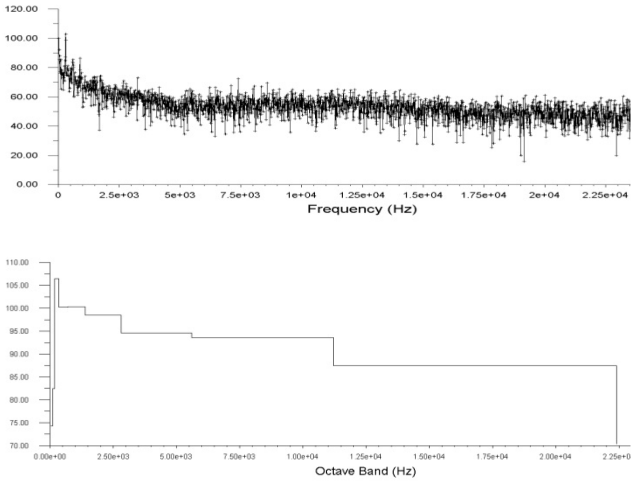


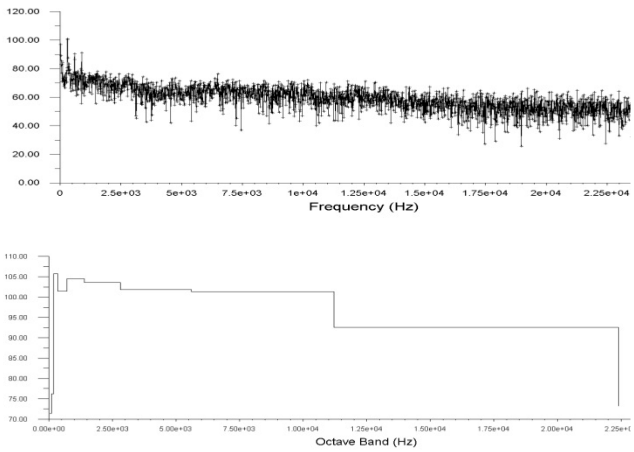
Fig. 5. Acoustic Power Level (dB) of the Rotors

Second, the results at each receiver locations of the transient analysis are plotted in Figure 6 for the Sound Pressure Level (SPL) of both unweighted and A-weighted. Unweighted SPL is checked to see the frequencies where the peak SPL occurs. Then the A-weighted SPL is checked to calculate the overall sound level result. A-weighting filter is known as a filter that simulates the response of the human ear by compensating for the lower sensitivity of the human ear to low frequency sound. The frequencies where the peak SPL occurs and overall sound level at each receiver location are listed in Table I. Then, the frequencies and overall sound levels were compared with the Blade Passing Frequency (BPF) and the test result respectively. The receiver locations are distant from the test location. The sound level test location is approximately 0.8 m right below the receiver-1 location.

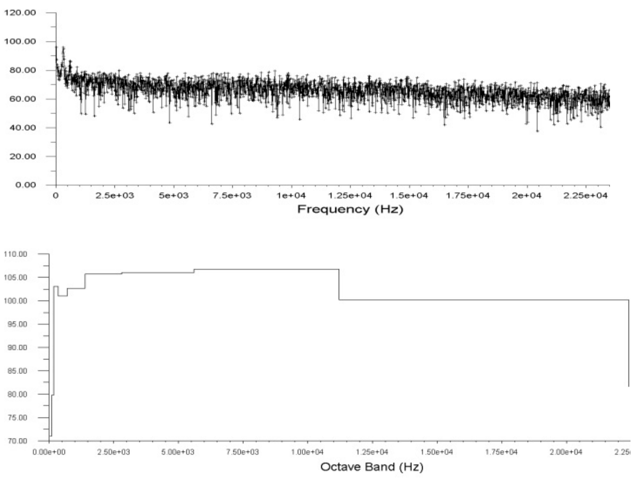
However, it is still meaningful to compare those results since the logarithmic characteristic of the decibel will show the reasonable differences against the difference in distance.



(a) SPL Result at receiver-1 [dB-upper, dB(A)-lower]



(b) SPL Result at receiver-2 [dB-upper, dB(A)-lower]



(c) SPL Result at receiver-3 [dB-upper, dB(A)-lower]

Fig. 6. Sound Level Analysis Results

Table I: Sound Analysis Results with Test Result

Locations	Frequency (Hz) at Peak SPL	Overall Sound Level-dB(A)
receiver-1	292.76	109
receiver-2	291.65	111
receiver-3	301.66	113
Test	295.83[1)]	105.3[2)]

Notes: 1) The value is BPF not the test frequency.
2) Test result is for the APR1400 IHA.

As shown in Table I, the frequencies where the peak SPL occurs are approximately 4 Hz differ from the BPF. The CEDM cooling fan has 2 rotating parts, and each of them has 10 blades rotating at 1,775 rpm. The overall sound level result of receiver-1, which is the closest location to the test location, is about 3.7 dB(A) higher than the test result. This sound level difference might be caused mostly due to the sound shield effect of the fan casing other than the location difference because the sound shield effect is not considered in this analysis.

The result of receiver-3 is the highest among the simulated locations. The location of the receiver-3 is in the middle of the air flow path. And the location of the receiver-2 is between the receiver-1 and receiver-3. So, it can be said that the flow path has the higher sound level.

2.4 Damper Effect Analysis Results

As described in the Sec. 2.2 of this paper, the flow rate and differential pressure across the fan with various damper angles have been studied to see the tendency against various damper angles. The results are tabulated in Table II below.

Table II: Damper Effect Analysis Result

Angle of the Damper	Flow Rate (CFM)	Differential Pressure Across the Fan (inches-Water)
0°	44,722	3.336
10°	44,612	3.417
20°	44,063	3.563
30°	43,867	4.038
40°	43,243	4.722

The differential pressure across the fan has significantly increased when the damper angel is greater than 20° as shown in Table II, while the flow rates of the analyzed results show no regularity. However, all the results show that the flow rate decreases and the differential pressure increases as the damper angle increases as expected.

3. Conclusions

In this paper, the sound level analysis and damper effect analysis have been performed for the CEDM cooling fan design using ANSYS Fluent. The first one has been performed to set up the simulation process. Then the results were compared with the test result.

The sound level result at receiver-1, which is the closest location to the test location, is relatively in a good agreement with the test result by the difference less than 4 dB(A). The sound shield effect of the fan casing will be included with the as-built geometry of the CEDM cooling fan for the sound level analysis in future. Further study will also be performed to minimize the overall sound level of the CEDM cooling fan since the sound level over 100 dB(A) can seriously damage the hearing ability of the operators if they work for a long period of time.

For the damper angle effects, the study has been performed with the butterfly type damper since it is considered in the improving IHA. The effects of the various damper angles with respect to the flow rate and differential pressure across the fan were studied to see the tendency. If the CEDM cooling fan has manufactured with some design margin in the flow rate, the control of the damper angle will be possible within the limit of the design requirements. In the future, transient analysis will be performed to generate more reliable results.

In short, the sound level analysis and damper effect analysis have been performed in this paper. The one was studied to set up the sound level analysis method and procedures, and the other was to approximately compute the damper angle effects. The rigorous analysis will be performed with the as-built information of the CEDM cooling fan in future.

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