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NOISE CONTROL ENGINEERING BY SOUND-STRUCTURE INTERACTION ANALYSIS

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ABSTRACT
The paper describes a design method for the cyclone separator by combined fluid and structural mechanics technology. It is well known that cyclone separators are designed based mainly on manufacturer's experience. Performance of particle separation and the noise level emitted from cyclone separator are difficult to be predicted prior to plant start-up. Proposed design method of the cyclone separator, using fluid and sound-structure interaction analysis during engineering stage, successfully achieved collection of particles with high performance and prevention of noise.

1 - INTRODUCTION
Basic design and detail engineering for industrial plants shall be carried out by estimating operation performance after plant start-up, or operability in assumed layout for plant, equipment and piping, etc. In addition, it is necessary to consider the suitable environment for operators in work area and for neighborhood communities. Experiments using test model for large equipment and many complicated pipes including various operation cases are not simple, because process plants are not mass-produced but made to order based on individual process and requirements / regulations for each country. Therefore, numerical simulations for the fluid, vibration, and acoustic problems are key tools for the engineering.
The design method by sound structure interaction analysis has been applied mainly for vehicles and aircraft, but not for the cyclone separator (a special purpose equipment for gas-particle separation) so far.
For cyclone separator, optimum design by fluid analysis and the noise abatement by sound-structure interaction analysis are actively carried out by the authors to obtain high performance and prevent problems in relation to acoustic resonance and vibration. It is predicted by present acoustic analysis that the high noise would be transmitted through the cyclone separator's wall and radiated to outside because the resonant frequency of acoustic standing wave inside the separator coincides with the structural mode. For the prevention of this problem, optimum sizing and noise countermeasures for the cyclone separator are taken during engineering stage, and the effectiveness is verified after plant start-up [1].

2 - DESIGN BY COMBINED FLUID AND STRUCTURAL MECHANICS TECHNOLOGY
When a problem occurred during operation of the cyclone separator, any remedial work for improving performance of separation or noise reduction would require costly redesign, reconstruction of process and structure. In this paper, a design method of cyclone separator is presented where the combined fluid and structural mechanics technology simulating many cases of operation is applied during engineering stage and improvement in separation performance as well as noise reduction was achieved.

2.1 - Design by fluid analysis
For basic design of the cyclone separator in order to achieve the high performance of separation, Computational Fluid Dynamics (CFD) is applied for main fluid analysis. Some case studies are carried out by changing the parameters of particle mass and gas flow rate. From trajectories of particles from the

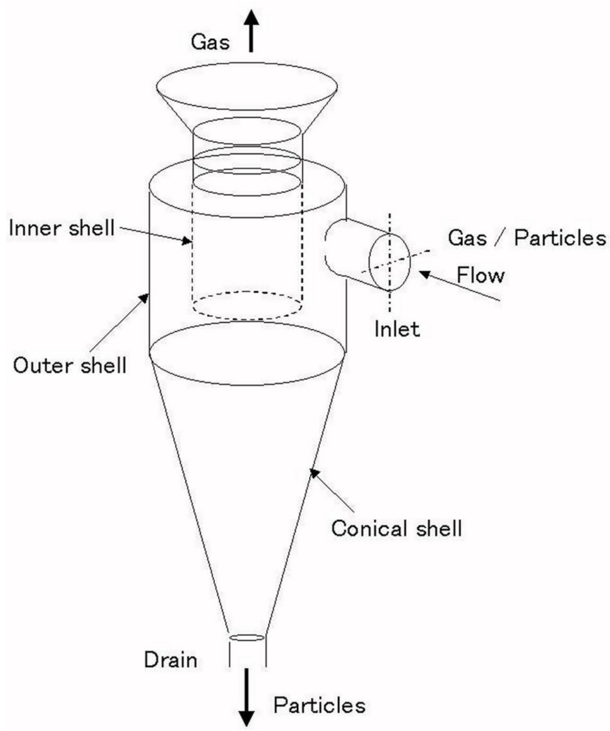

Figure 1: The model of a cyclone separator.

inlet pipe to the drain as shown in Fig. 2, it is found that an increase in particle mass and in flow rate is able to improve the separation performance of the cyclone separator.
When either gas velocity or particle mass is increased, the friction between particles and wall inside the separator is increased at the same time based on the centrifugal force. Therefore, the particles reside for a while inside the cyclone separator and finally flow to drain. Important points in cyclone separator's design to achieve high performance of separation are summarized as follows:
Optimum sizing for

- Configuration of separator shell and drain
- Length and angle of conical part

However, it is possible that the above mentioned optimum design may sometimes cause noise problem or high velocity of gas inside the separator, i.e. the flow noise may be excited at the resonance frequency of the enclosed space inside the separator. In order to overcome this noise problem, sound-structure interaction analysis has been carried out as a next step for the cyclone separator design based on the fluid analysis.

2.2 - Noise abatement design by acoustic analysis
After the basic design by fluid analysis, acoustic analysis including sound-structure interaction is carried out to predict the noise level and prevent noise problem in relation to acoustic resonance and vibration in advance. We have used a main solution program (SYSNOISE: developed by LMS Numerical Technologies) for 3-dimentional acoustic analysis based on Finite Element Method (FEM) / Boundary Element Method (BEM). Details of engineering method with example are described as follows:

2.3 - Frequency response inside cyclone separator
As shown in Fig. 3, frequency range between 200 Hz and 700 Hz has been chosen for acoustic analysis based on the experience of noise matters for cyclone separator. Nine (9) peaks has been detected as the resonance frequencies inside the cyclone separator. This 9 peaks depend on the inner size of the enclosed space (shell, conical part and inlet pipe). Sound Pressure Level (SPL) at each peak frequency is higher (10dB-25dB) than the input SPL, which is considered as flow induced noise.

2.4 - Comparison between acoustic resonance frequency and structural mode
To study the coincidence between acoustic resonance frequency and structural mode, structural analysis is applied to the cyclone separator model. From Table 1, we can see that all 9 peaks of acoustic resonance

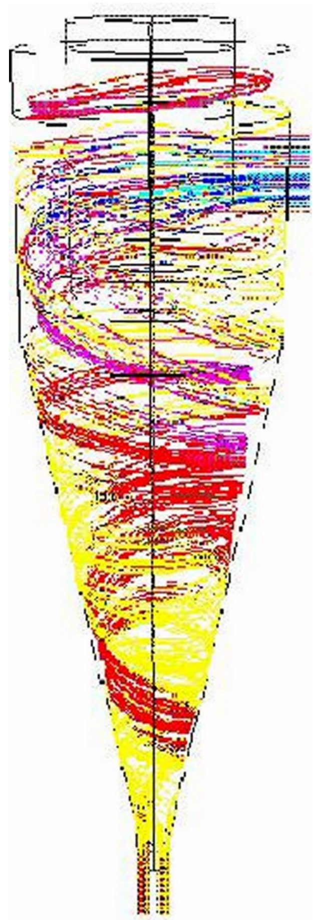

Figure 2: Example of fluid analysis.

frequencies are close to structural modes, and therefore, the cyclone separator has the possibility of causing noise transmitted through the shell and radiated to outside in spite of the acoustic transmission loss at the steel, i.e. outer shell of the separator.

No.	Acoustic mode		Structural mode
	Frequency (Hz)	Acoustic Resonance Location	Frequency (Hz)
1	260	Outer shell	255, 261, 264
2	370	Outer shell	366, 367, 371, 372
3	410	Outer shell	408, 409, 412, 415
		Conical shell	
4	460	Outer shell	456, 458, 460, 462
		Conical shell	463, 464
5	490	Outer shell	486, 490, 492
6	550	Outer shell	548, 550, 554
		Conical shell	
		Inlet piping	
7	590	Outer shell	589, 590, 593
		Conical shell	
		Inlet piping	
8	640	Inlet piping	635, 636, 642, 645
9	680	Outer shell	676, 678, 679, 683
		Conical shell	684, 685
		Inlet piping	

Table 1: Summary of resonance frequency.

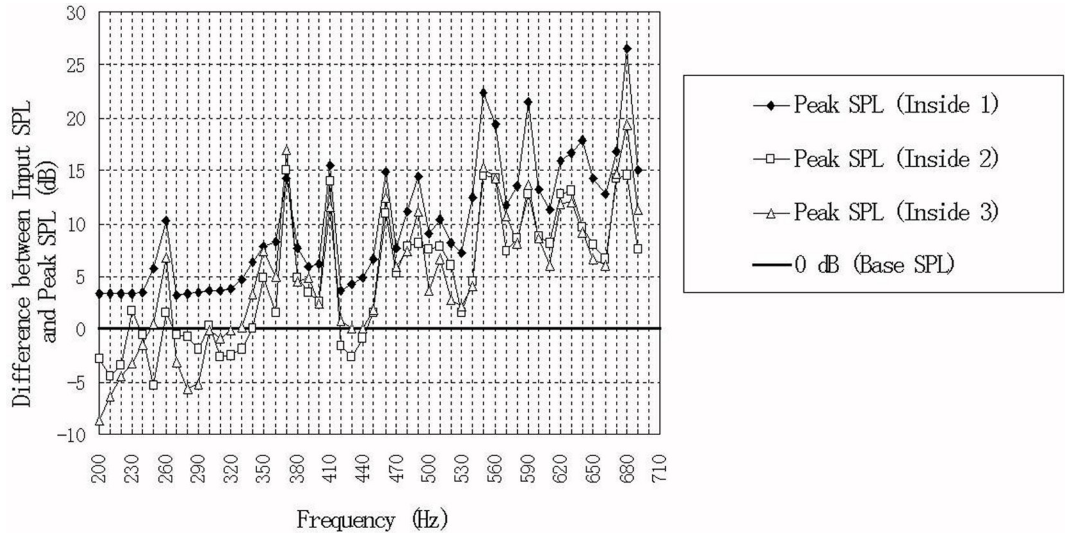

Figure 3: The frequency response inside cyclone separator.

3 - EXPERIMENT FOR NOISE AND VIBRATION

Speaker and hammering tests for noise and vibration have been carried out at the shop before installation of the separator in plant, in order to specify remarkable frequencies not only by computational analysis but also by experiment. These test methods are as follows:

- Speaker test
  Pink noise and pure tone noise from a noise generator are provided from the inlet pipe. Microphones are installed inside and outside of the cyclone separator to measure the acoustic transmission loss at the shell. The noise levels inside and outside of the cyclone separator are recorded on a digital audio tape recorder for spectrum analysis.
- Hammering test
  To confirm the structural mode, the cyclone separator (shell, conical part and inlet pipe) is hammered by using a hammer. The noise emitted from the cyclone separator is recorded on the digital audio tape recorder for spectrum analysis.

Results of the speaker test are shown in Table 3, some resonance frequencies including those predicted by the acoustic analysis were observed between 200 Hz and 700 Hz. Attention shall be paid to SPL outside of the cyclone separator at 260, 460 and 590 Hz, because the resonance frequencies at 260, 460, 590Hz were appeared not only by speaker test but by the hammering test as well. On the other hand, regarding 370Hz of resonance frequency inside the cyclone separator which is also confirmed as a structural mode of shell, SPL outside of the cyclone separator was not increased by the speaker test. Therefore the acoustic radiation efficiency of cyclone separator at 370Hz is not expected to be remarkable.

4 - PREDICTION OF NOISE EMISSION BY SOUND-STRUCTURE INTERACTION ANALYSIS

It is possible that the high noise at some frequencies shown in Table 3 would be transmitted through the cyclone separator's wall to outside by the flow induced noise and the collision between particles and shell during operation of the separator. Based on the result of the analysis in Sec. 2 and the experiment in Sec. 3, noise countermeasures have been taken by installation of acoustic insulation in the cyclone separator and associated pipes in order to comply with the noise limit of work area in plant and neighborhood community. The noise level outside the cyclone separator with the noise countermeasure is predicted by the sound-structure interaction analysis. The difference between input SPL and outer SPL shown in table 2 is predicted approximately 25 dB at 260 Hz and 15 dB at 460 and 590Hz.

Frequency	Difference between input SPL and outer SPL (dB)
260Hz	Approx. 25dB
460Hz	Approx. 15dB
590Hz	Approx. 15dB

Table 2: Summary of frequency response by sound-structure interaction analysis.

Freq. (Hz)	Acoustic Analysis	Experiment for Acoustic / Vibration	Measurement for Acoustic
260	*	*	*
370	*		
410	*	*	*
460	*	*	*
490	*	*	*
550	*		*
590	*	*	*
640	*		*
680	*	*	*

Table 3: The summary of analysis-experiment-measurement results (*: peak frequency).

Fig. 4 shows the noise contour map inside the cyclone separator by acoustic analysis, 1 meter apart from the separator's surface by sound-structure interaction analysis, and the structural mode shape by structural analysis at 590 Hz considering the noise countermeasure. The phenomenon of noise emission from the shell part of the cyclone is found that the noise level around the shell is higher than other parts. However, outer SPL is expected to have no effect in the work area in plant and neighborhood community because of the noise reduction by the acoustic insulation.

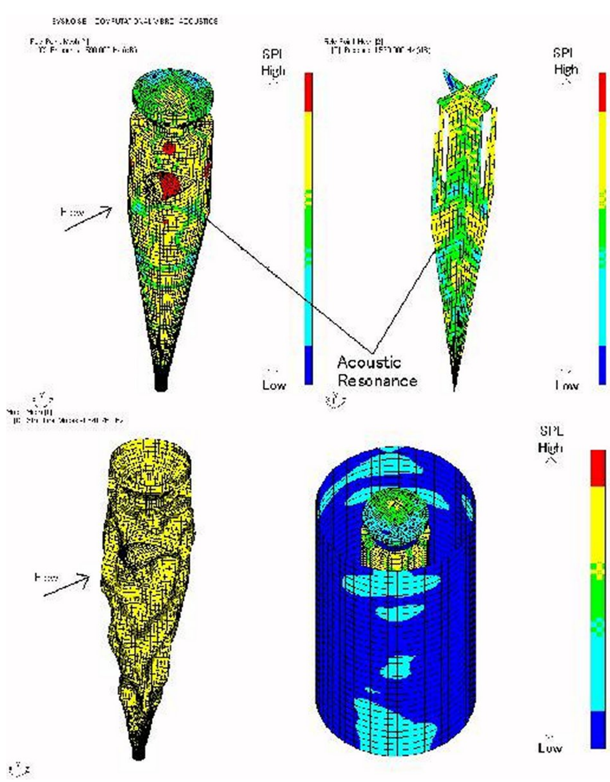

Figure 4: The noise contour map of sound-structure interaction analysis.

5 - VERIFICATION OF ANALYSIS

In order to verify the result of present analysis, amounts of collected particles and the noise level emitted from the cyclone separator have been measured at site after plant start-up. Results of the measurement are summarized as follows:

- Verification of separation efficiency
  Designed amounts of particles have successfully collected from the drain of the cyclone separator.

- Verification of noise level
  By the measurement of the noise level at a place 1 meter apart from the cyclone separator's surface, we have seen that the noise level is less than the noise limit of the cyclone separator. Analysis, experiment, and measurement results for noise are summarized in Table 3. Some peak frequencies obtained by noise measurement coincided with resonance frequencies based on acoustic analysis and experiment. The optimum noise countermeasure designed at engineering stage proved to be quite successful because the peak frequencies during operation were expected by analysis and experiment. Furthermore, SPL at 590 Hz obtained by measurement satisfactorily agreed with those predicted by the sound-structure interaction analysis.

6 - CONCLUSION

Proposed design method of the cyclone separator, using combined fluid and structural mechanics technology with fluid and sound-structure interaction analysis during engineering stage, successfully achieved collection of particles with high performance and prevention of noise. It is also advantageous for engineers to predict the performance of cyclone separator prior to the plant start-up. This engineering approach by using analysis as an experiment is considered to be effective for construction of process plant.

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