STUDY OF SOUND SOURCE DISTRIBUTION IN CENTRIFUGAL FAN USING TRANSPARENT WALL

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SUMMARY

It is proposed the use of the transparent wall for the research of the sound source characteristics of the centrifugal fan. A part of the casing wall is replaced from the solid wall to the transparent wall. The transparent wall plays the wall for the air flow but passes through the sound. The characteristics of the transparent wall are discussed at pressurized condition. It is cleared that the transmittance of the transparent wall is gradually decreased with the pressure and significantly decreased at low frequency. The transparent wall is adopted to the centrifugal fan for pressurized operation. It can be decreased the interaction for the sound propagation in the fan. And the sound radiation from the rotating blade is well observed with the transparent wall. It is indicated the ability of the transparent wall for the sound source analyzing of the fan.

INTRODUCTION

It is important to analyze the characteristics of the sound source of the fan to reduce the fan noise. The sound holography and beamforming methods are recently improved for this purpose, but it needs the bared sound source for these methods. These methods have developed for the axial fan, because the blades, the main sound sources of the fan, are not covered with the casing in inlet or outlet path and are visible from the microphone array [1],[2].

But it is difficult to use these methods for the centrifugal fan because the blades are covered with solid casing and hidden from the microphone array. Figure 1 shows the images of the sound radiation in the centrifugal fan. figure 1(a) is the case of the solid wall casing. The main sound sources on the blades are blocked by the casing. The interaction of the sound is occurred in the casing wall, so it is difficult to analyze the sound source characteristics with the microphone array. For the research of the sound source characteristics of the centrifugal fan, we propose to use the transparent wall. Transparent wall is attempted by some researchers for the purpose of the reduction of the noise and analyzation the sound source map for the simple cases [3]-[5]. But the application for the fan is not existed. Figure 1(b) shows the image of the transparent wall casing. The transparent wall plays the wall for the flow of air, but not the wall for the sound. The sound does not interact in the casing and directly radiates to the outer-ward of the transparent wall casing. The casing performance for the air flow is almost same to the solid wall. It can make the pressurized condition of the fan and measure the sound radiation through the transparent wall. It makes easy to analyze the characteristics of the sound source for the various flow rate and pressurized conditions.

In this paper, the characteristics of the transparent wall is analyzed at the pressurized condition. And the transparent wall is adopted to the centrifugal fan that measures the sound radiation from the fan. It is indicated the potential of the transparent wall for the use of the sound source analysis.

EXPERIMENTAL METHODS

Transparent wall

The transparent wall is consisted of the cloth, mesh and film. Figure 2 shows the example of the construction of the transparent wall and the photograph. Film blocks the air flow, but not blocks the sound. The wire mesh keeps the wall shape against the inner high pressure. The front cloth prevents to generate the noise by the turbulence when the air flow directly strikes to the film and the rear cloth keeps the vibration without adhere the film to the mesh.

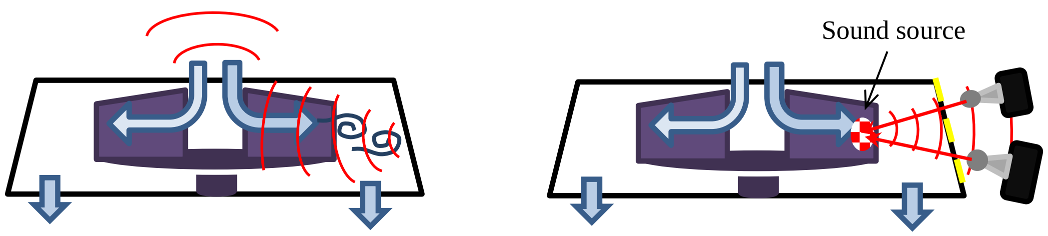
It is assumed the plane wave normal to the wall. The transparent wall is very thin compared to the sound wave length, and so the damping and the phase change is not occurred at the transparent wall. The transparent wall is regarded as the thin film. The transmittance *t* of the film is estimated by the following equation [7].

$$t = \left\{ \frac{2}{2 + \left| Z / (\rho_0 \cdot a_0) \right|} \right\}^2 \qquad (1)$$

The impedance *Z* of the film to the sound transmission is given by the following equations that is relating to the sound propagation with the transparent wall and the vibration of the thin circular film of diameter *D*.

$$Z = j \frac{\rho_m \omega}{\dfrac{1}{J_0(q \cdot D/2)} - 1} \qquad (2)$$

Where $J_0()$ is the Bessel function, ρ_m is the area density, ω is the angular frequency of the sound and



(a) Solid wall casing *(b) transparent wall*

Figure 1: Image of casing influence in the fan

q is given by $q = \dfrac{\omega}{\sqrt{T/\rho_m}}$. T is the tension of film that is caused by the pressure P at the inner side of the transparent wall and given by the following equation.

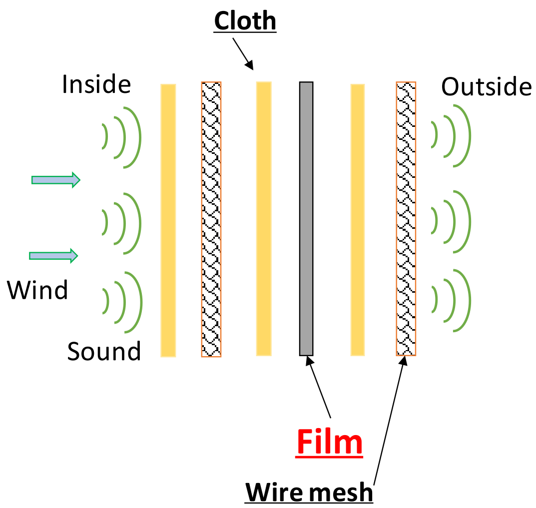
$$T = \frac{P \cdot D}{4\sin\left(\sqrt[3]{-\frac{\beta}{2}+\sqrt{\left(\frac{\beta}{2}\right)^2+\left(\frac{\alpha}{3}\right)^3}}+\sqrt[3]{-\frac{\beta}{2}-\sqrt{\left(\frac{\beta}{2}\right)^2+\left(\frac{\alpha}{3}\right)^3}}\right)}, \quad \alpha = \frac{6T_0}{m(1+\nu)-T_0}, \quad \beta = \frac{-3PD}{2\{m(1+\nu)-T_0\}} \qquad (3)$$

where $m = \dfrac{Eh}{1-\nu^2}$. E is Young's modulus, h is thickness of film and ν is Poisson ratio. The film is set with the initial tension T_0.

Centrifugal fan

Figure 3 shows the schematics of the centrifugal impeller. The inner diameter at the hub and shroud are 55 mm and 85 mm. The eye diameter is 100 mm, so the leading edge of blade is just out over the bell-mouth. The outer diameter of the impeller is 140 mm. The span at outlet of impeller is 15 mm. The blade is 3 mm of the thickness and the two -dimensional geometry. The number blade is 9 [6].

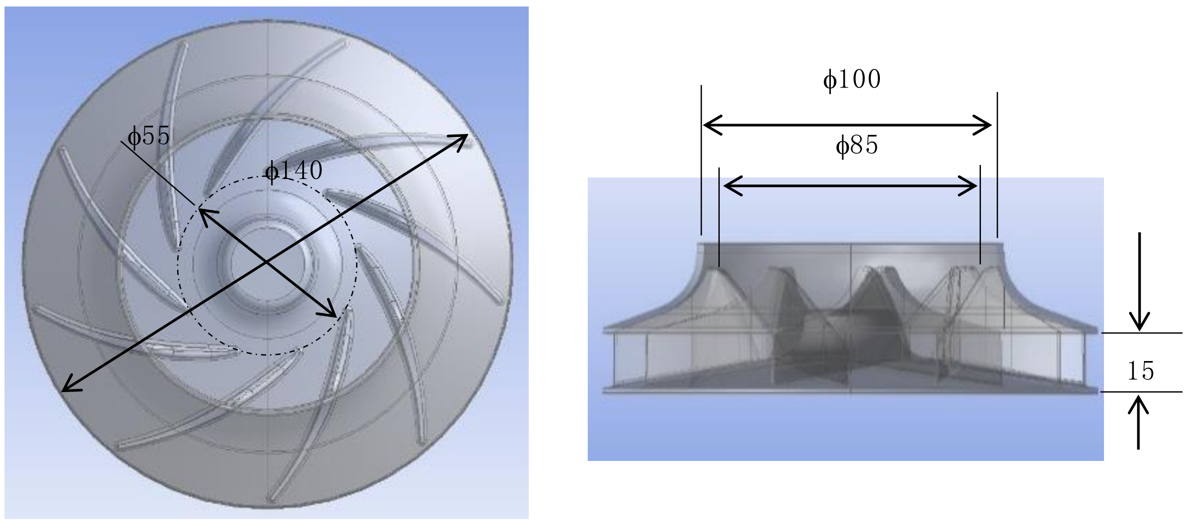
Figure 4 shows the schematics of the casing geometry. Figure 4(a) is the main dimension of the casing. The casing is tapered that the diameter is gradually increased from ϕ 173 mm to ϕ 249 mm. The axial length of the casing is 62.5 mm, of which the upper part of 27 mm length is corresponding to the outlet of the impeller. The inner side of the downstream duct is tapered, so the section area of the casing is gradually increased downstream of the impeller. Figure 4(b) is the solid wall casing. The left figure is the skeleton and right one is photograph of casing. This wall is made by 3D printer and the surface of the wall is rough [6]. Figure 4(c) is the transparent wall casing. The solid wall is remained at upper and lower parts. Only the part of the impeller outlet is set to the transparent wall. The right photograph shows the casing before the transparent wall setting and it is observed the supports to connect the upper and lower parts of the casing.



(a) structure of transparent wall

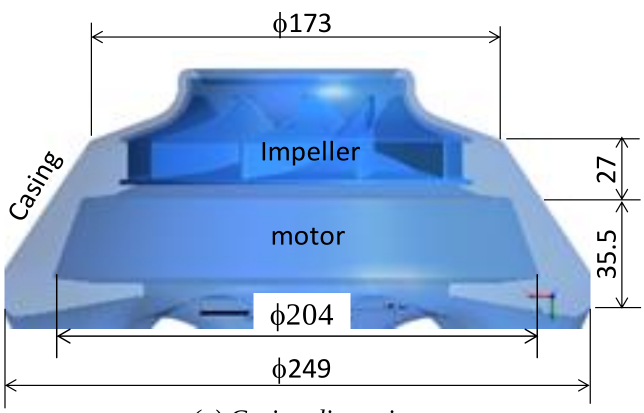
(b) Outer surface of transparent wall

Figure 2: Example of transparent wall



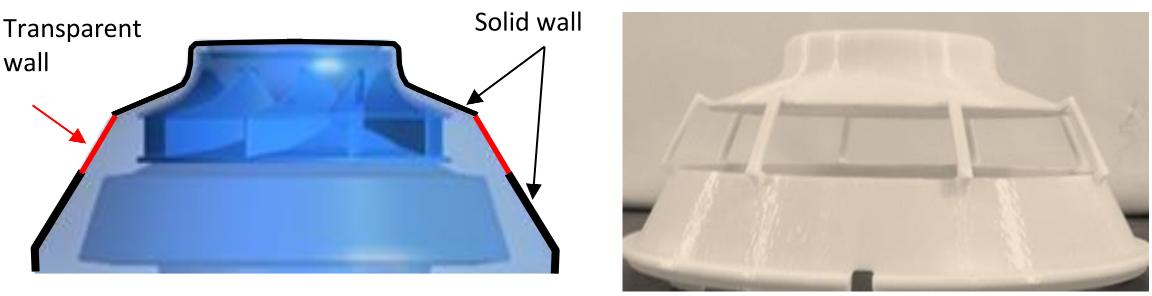
(a) Front view *(b) Side view*

Figure 3: Schematics of Impeller



(a) Casing dimensions

(b) Solid wall



(c) Transparent wall

Figure4: Schematic of solid wall casing and transparent wall casing

Experimental methods

The fan performance is measured with anechoic chamber. The noise level is measured with the precision sound level meter at the 1 m and 0.1 m upstream from the bell-mouth. The sound characteristics at near field are measured 30 mm upstream from the bell-mouth by the microphone array. Figure 5 shows the microphone array setting in front of the fan with the transparent wall. It is worry about the interaction of the inflow with the microphone array, but it is similar to the practical use of this fan that the obstacles exist at front of fan, cover support, mesh and others. The microphone array is consisted with 6-rows and 5-lines microphones with plane arrangement.

Simulation methods

The flow simulation is made by the commercial code ANSYS CFX 14.5. The steady Reynolds Averaged Navier-Stokes(RANS) simulation is performed for the impeller and inlet and outlet flow domains. The turbulent model is SST. The total number of elements are about 14 million of tetra mesh. The inflation is set y+ = 10 on the blade and casing surface. The flow rate is set at the inlet boundary [6].

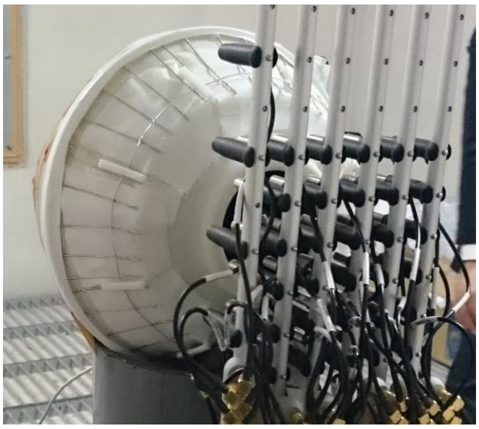


Figure5: Photograph of microphone array arrangement in front of the fan.

RESULTS AND DISCUSSIONS

Characteristics of transparent wall

Figure 6 shows the estimated transmittance with equation (1) for each pressure of inner side of the wall. The film is made from Polyvinylidene chloride. The thickness is 11 μm. The Young's modulus is 400 MPa, Poisson ratio is 0.3. The area density is 0.0187 kg/m^2. The film is drawn with the initial tension 5 N/m to keep the flat wall. The transmittance is gradually increased with the frequency. The transmittance is about 1.0 over the 500 Hz. When the inner pressure increases, the curves of the transmittance become low in all frequencies. Especially the decrement of the transmittance is large at the small inner pressure.

Figure 7 shows the octave distributions of the transparent sound with experiments [7]. The sound pressure levels are almost same to the case of without-wall (W-O) at high frequency. This indicates that the sound almost passes through the transparent wall at high frequency. But at low frequency, the sound pressure levels become low with high inner pressure. The decrement of the sound pressure level is large at small inner pressure that is well agreed with the estimated results shown in figure 6. The decrement of the sound level is varied with the inner pressure and other parameters; the wall size, film thickness and Young' modulus [7].

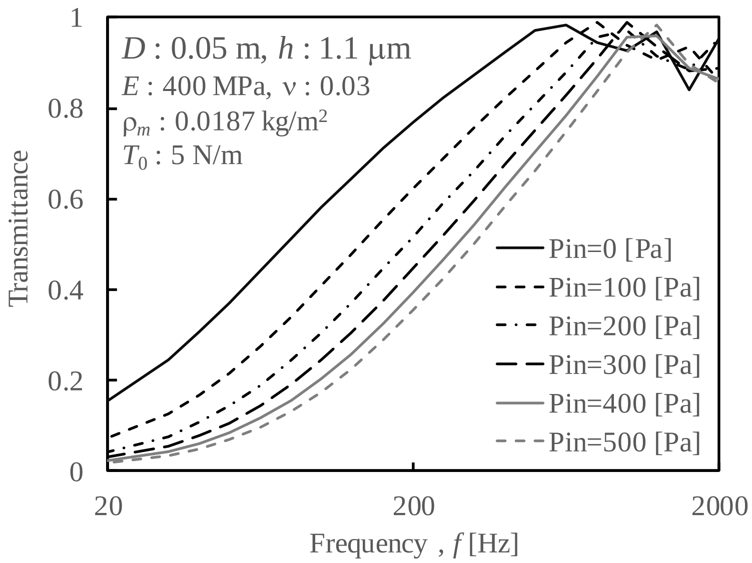


Figure 6: Estimation of transmittance of transparent wall for each inner pressure of inner side of the wall.

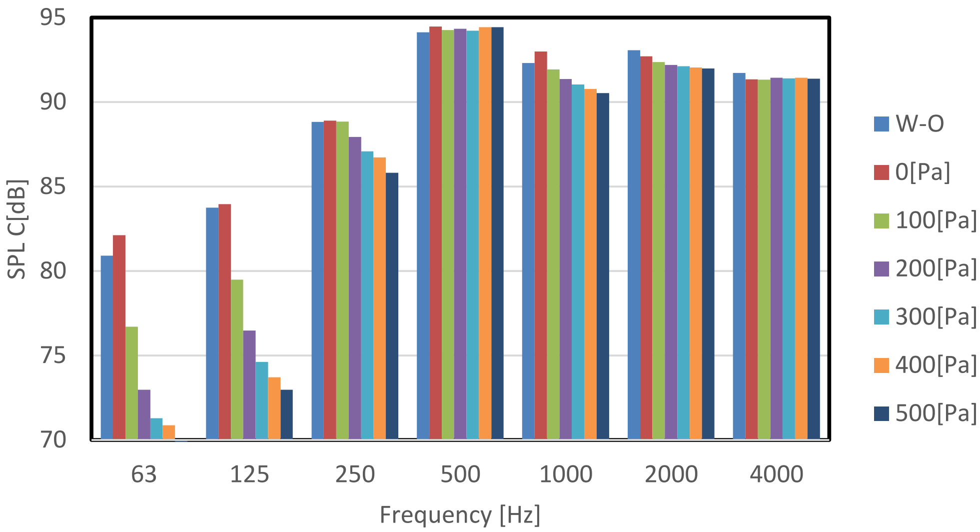


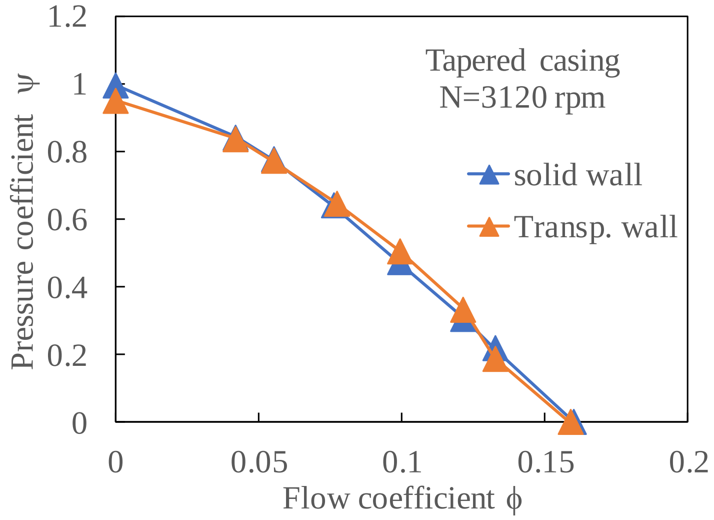
Figure 7: Octave distribution of transmittance for transparent wall in experiments

Fluids and Noise Performances

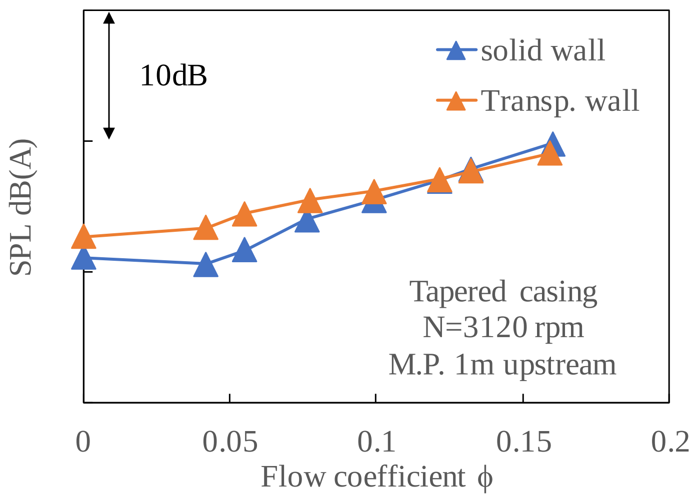
Figure 8 shows the fluid and noise performances in experiments [6]. The performances are compared for solid and transparent wall. Figure 8(a) shows the variation of the pressure coefficient with flow coefficient. The pressure coefficient of transparent wall is well coincident to the solid wall at all flow rates. This shows that the transparent wall does not change the fluid performance. Figure 8(b) shows the overall sound pressure levels. The sound level is almost same at the large flow coefficient over the design flow rate, ϕ=0.12. But at the low flow coefficients, the sound level at the transparent wall is larger about 2-3 dB than the case of the solid wall. This is caused by the unstable flow induces the vibration of the transparent wall and generates the sound at the transparent wall.

Flow Characteristics

Figure 9 shows the simulation result. The relative velocity vector map is presented at the outlet of the impeller [6]. The flow coefficient is 0.12, design point. There exists the large separation region near the trailing edge of the suction surface. Then the flow is gathered to the pressure side and main flow velocity becomes large at the trailing edge. The frequency of the turbulent noise from the blade is estimated mainly 200-700 Hz from Fukano's [8] or Proudman's [9] estimations by using the simulation results.



(a) Fluid performance



(b) Noise performance

Figure 8: Comparison of Fluid and noise performances

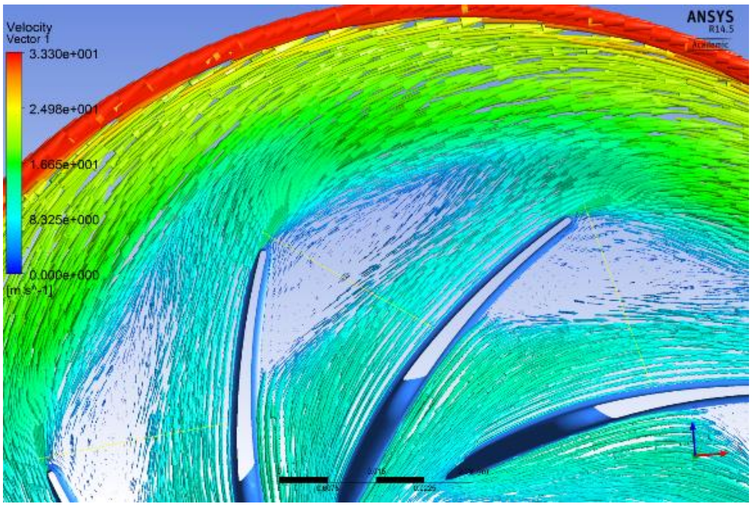
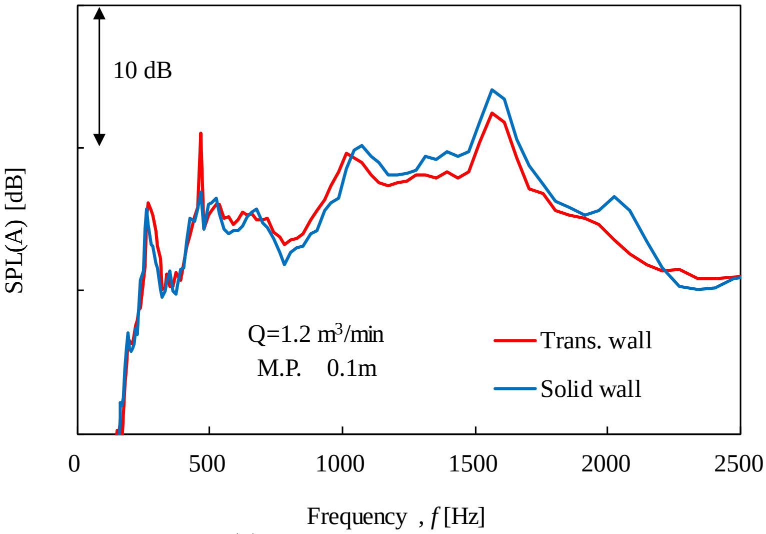


Figure 9: Velocity vectors near the impeller outlet (flow coefficient: 0.12)

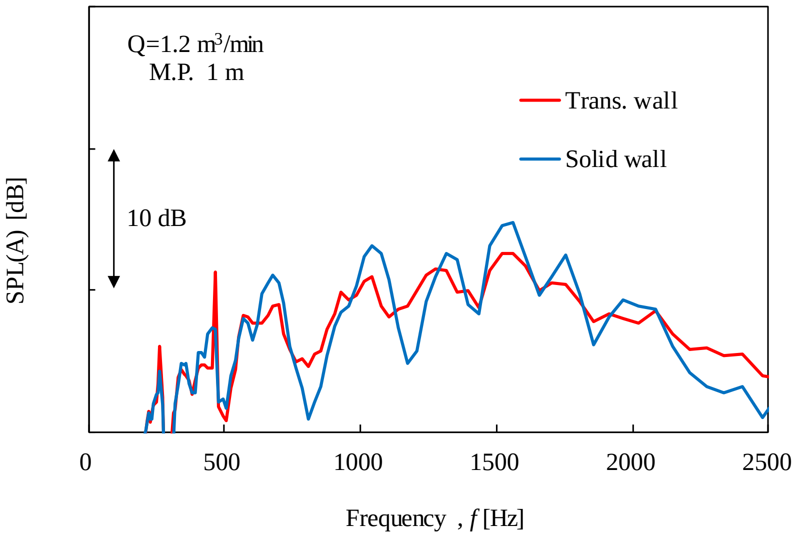
Sound Characteristics

Figure 10 shows the spectrum distributions of the sound pressure level. Figure 10(a) is the near field distributions at 0.1 m upstream of bell-mouth. There exists the discrete frequency noise near the 500 Hz, and the broadband noises at 200-700 Hz and 1000-2000 Hz. The peaks near the 500 Hz is remarkable at transparent wall, but not clear at solid wall. This is caused by the interaction of the sound with the solid wall in the casing. Figure 10(b) is the far field spectrum distributions. The peak near 500 Hz is remarkable at transparent wall, too. The broadband noise of solid wall is different from the near field spectrum distributions. But the variation with the near field distribution is small at transparent wall. This indicates that the radiation pattern is different with the casing wall condition.

Figure 11 shows the instantaneous sound radiation map at the frequency 500 Hz at the bell-mouth plane. Figure 11(a) is the case of solid wall. The large sound level at the bell-mouth section is entirely mapped and the distribution is hardly changed in time, and so it is not clear the sound source. It is caused by the interaction of the sound with the casing solid wall in the fan. Figure 11(b) is the case of the transparent wall. The large sound level is located near the lower part of the bell-mouth and the large sound part is rotating in time. The sound characteristics is relatively clear. The transparent wall reduces the interaction and reflection of the sound with the casing wall and makes clear the characteristics of the sound generation.

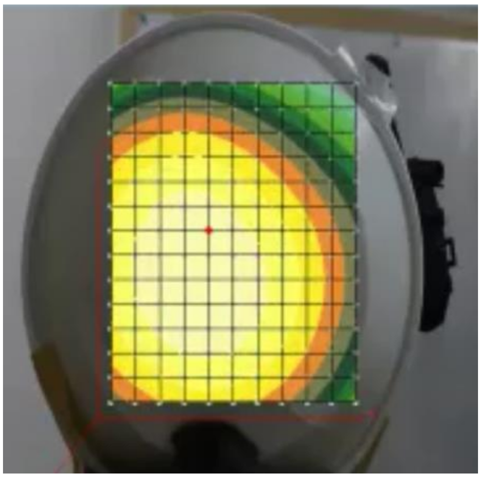


(a) Measuring point 0.1m

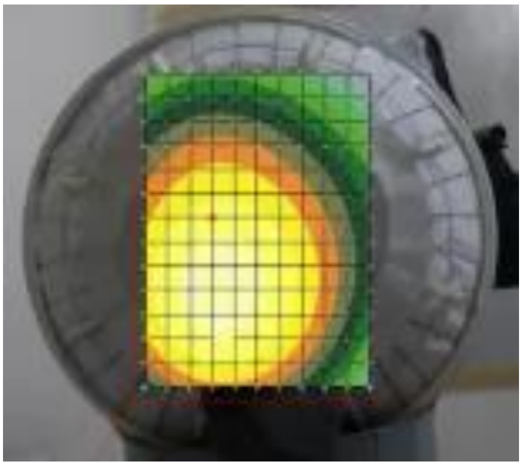


(b) Measuring point 1.0m

Figure 10 Spectrum distributions of sound radiation from the fan (flow coefficient: 0.12)



(a) Solid wall



(b) transparent wall

Figure 11: 500 Hz sound map at bell-mouth (*flow coefficient: 0.12*)

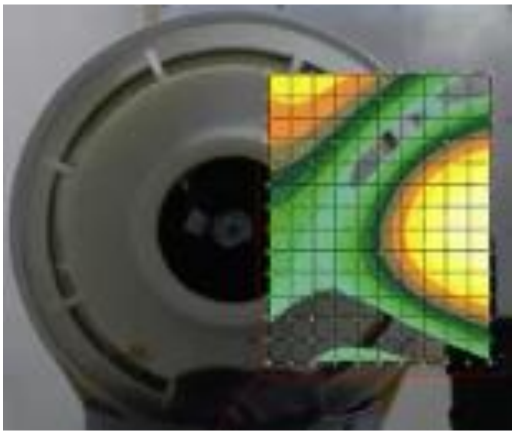


Figure 12: 500 Hz sound map at impeller shroud plane (*flow coefficient: 0.12*)

Figure 12 shows the sound radiation map of frequency 500Hz sound passing through the transparent wall. It can be seen the large part out of the transparent wall casing. The distribution is moved with the impeller rotation. This shows the possibility of the investigation of the sound source characteristics in the pressurized condition of the centrifugal fan.

CONCLUSIONS

It is proposed the use of transparent wall for the research of the sound source characteristics of the centrifugal fan. The following results are obtained.

1. The transmittance of the transparent wall is varied with the pressure. The transmittance decreases with the pressure at the low frequency.
2. The flow characteristics in the fan is not changed with the transparent wall use.
3. It can be decreased the interaction at the propagation in the fan and the radiation of the sound through the transparent wall is cleared.
4. It is shown the ability of transparent wall use for the sound source analyzing in the fan.

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