Journal of Thermal Science

DOI:

Noise Characteristics of Centrifugal Blower with Low Solidity Cascade Diffuser (Noise Reduction by means of Small Groove Located at LSD Blade Leading Tip)

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This paper deals with the effect of the blade tip-groove of the low solidity cascade diffuser (LSD) on the blower characteristic and the noise generated by the LSD. The small grooves were set up at the root and/or tip near the leading edge of the LSD blade. In order to clarify the mechanism of noise increase due to LSD and also to reduce the noise, the relationships between the noise increase based on the LSD, the LSD performance and the secondary flow formed additionally by the tip-groove were investigated experimentally as well as numerically, especially analyzing flow behaviors in the LSD in view points of flow separation on the suction surface of the LSD blade and the secondary flow on the side walls. By reducing the stagnation region smaller near the root and/or tip of the LSD blade leading edge, the secondary flow behavior changes remarkably around the LSD blade, as a result, the noise level and the blower characteristics vary. It can be concluded that, by means of a small tip-groove located only at the shroud side near the LSD blade leading edge, the noise generated by the LSD can be reduced without deteriorations of the LSD performance and the blower characteristics as well.

Keywords: Centrifugal blower, Low solidity cascade diffuser, Noise, Diffuser performance, Secondary flow

CLC number: Document code: Article ID:

Introduction

A high pressure ratio and a wide operating range are required in recent centrifugal compressors and blowers. It is difficult, as is well known, to achieve both of a high pressure ratio and a wide operating range simultaneously. In order to achieve a wide flow range as well as a high efficiency, a low-solidity circular cascade diffuser was proposed firstly by Senoo et al.[1]. Hayami et al.[2] developed the LSD for transonic diffuser and the effectiveness of the LSD was demonstrated in their experiment. However, it has been found that, in the case of LSD, the typical discrete frequency noise increases due to the interaction between the impeller and the stationary diffuser blades. The authors [3] studied the effect of the LSD blade leading edge location on the diffuser performance and the sound pressure level experimentally in a centrifugal blower with different LSD blade leading edge locations. It was found that the increase in noise due to LSD is dependent mainly on the broadband noise and secondarily on some kinds of discrete frequency noise. The typical discrete frequency noise corresponding to the blade passing frequency (BPF) is due to the jet-wake flow interaction and the potential interaction between the rotating impeller blade and the LSD blade. The broadband noise increases with the lift force of the LSD blade, then, the noise increase due to the LSD seems to be mainly caused by the pressure fluctuation induced by the vortex shedding from the LSD blade surface. In this case, the noise was decreased without deterioration of the dif-

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fuser performance by locating the LSD leading edge at R_{LSD}= 1.20 where the jet-wake flow is almost completely uniformalized.

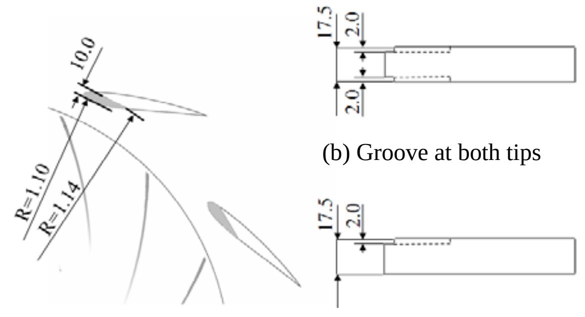
The objective of the present study is to reduce the noise due to LSD without moving the LSD blade leading edge downstream. The discrete frequency noise of the BPF is caused by the stagnation condition around the LSD blade leading edge, then, by setting up a small groove at the root and/or tip of the LSD blade leading edge, the stagnation region becomes smaller and the jet-wake interaction must become smaller, in addition, the changed stagnation condition results in changes in pressure fluctuation on the LSD blade surfaces and the path of the secondary flow around the LSD blade as well. In the present study, the relation between the broadband noise dominant in the overall noise level and the additionally generated secondary flow due to the tip-groove of the LSD blade were investigated with the help of numerical flow analysis.

Experimental and numerical simulation

The tested centrifugal impeller has the exit diameter of 510[mm] and sixteen 45[deg] backward leaning blades. The exit blade height is 17.0[mm], and the axial clearance between the impeller shroud tip and the shroud casing is 1.0[mm]. The U.S.A. 35-B airfoil was adopted as the LSD blade. The number of the LSD blade is 11 and the solidity of cascade was 0.693. The impeller was operated at a constant speed of 2,000[rpm], and the air was discharged axisymmetrically from the diffuser exit with its radius ratio of about 1.6.

Figure 1 shows the location and the shape of the LSD blade with small tip-grooves near the leading edge. The LSD blade leading edge was located at the radius ratio of R=1.10 downstream of the impeller as shown in Fig.1(a), and the tip-groove configuration is shown by the gray portion between R=1.10 and 1.14. The tip-groove was 2[mm] in depth as shown in Figs. 1(b) and (c); (b) shows the case with grooves at both side tips and (c) shows the case with a groove only at the shroud side tip. The setting angle of the LSD blade was fixed at 24[deg] from the circumferential direction, which was equal to the average absolute flow angle discharged from the impeller at the design flow rate of ϕ=0.27. Noise was measured by means of the 1/2 inch condenser microphone (B&K 4189) with a windscreen, which was located at 100[mm] downstream from the diffuser exit. The noise spectra were analyzed by using the real-time FFT analyzer (CF-5210) produced by ONO SOKKI Co. Ltd.

In the numerical simulation, the flow was assumed to be incompressible and steady. The 3D turbulent flow was



(a) Tip-groove location (b) Groove at both tips (c) Groove at shroud tip

Fig.1 LSD blade location and tip-groove configuration

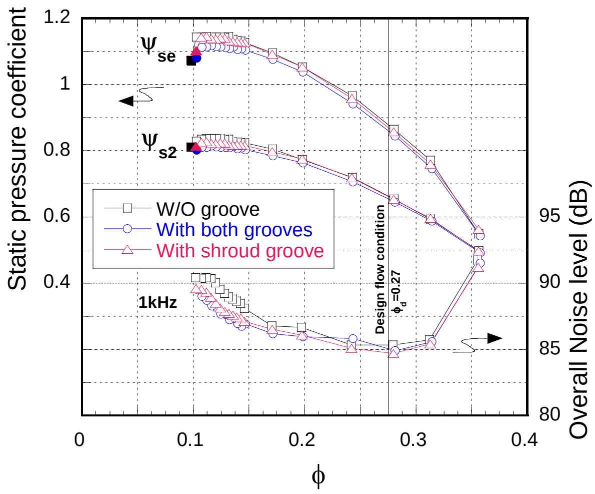


Fig.2 Effect of tip-groove on blower characteristics and overall noise level (Experiment)

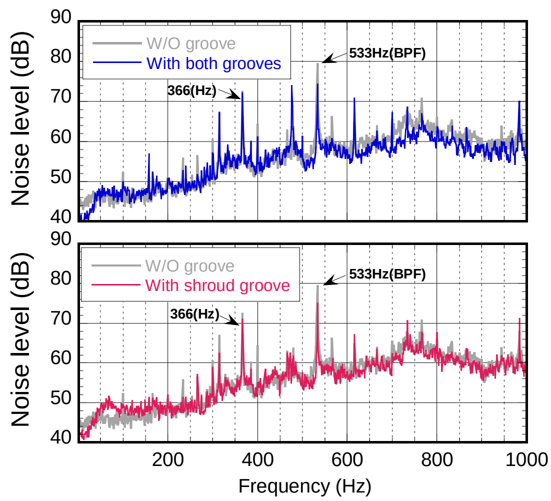


Fig.3 Comparison of frequency power spectra of noise between the cases with and without tip-groove measured at ϕ=0.13 (Experiment)

calculated by using the CFD code presented by

ANSYS-CFX with the k-ω turbulence model. The circumferential averaging method was adopted on the interface between the rotating frame and the stationary domain.

Results and discussions

Experimental results

Figure 2 shows the experimental results on the blower characteristics and the overall noise level, where the parameter is the tip-groove configuration. The abscissa is the discharge flow coefficient ϕ, and the left ordinate is the static pressure coefficient, in which ψ_{s2} denotes the static pressure coefficient at the impeller exit, ψ_{se} is the one at the diffuser exit. The right ordinate is the overall noise level. The solid mark denotes the flow rate at which the diffuser stall appeared. In the case of the LSD with the both tip-grooves, the overall noise level decreased about 2[dB] at the small flow rate, however, the diffuser exit static pressure coefficient ψ_{se} became worse about 3%. In the case with the shroud tip-groove alone, the overall noise level decreased also about 2[dB] in maximum at the small flow rate without deterioration of the blower characteristics.

Figure 3 shows the frequency power spectra of the noise level measured at the small flow rate of ϕ=0.13 in comparisons between the cases without tip-groove and with the both tip-grooves and between the cases without tip-groove and with the shroud tip-groove alone. The discrete frequency of 533[Hz] corresponds to the impeller blade passing frequency (BPF) and that of 366[Hz] corresponds to the product of the rotational speed of the impeller and the number of the LSD blades. As shown in Fig.3, the BPF noise level decreased markedly about 5[dB], and the broadband noise between 600-1000[Hz] also reduced remarkably about 2[dB] in the both cases with tip-groove compared with the case without tip-groove. Furthermore, the decrease of 2[dB] in the overall noise level shown in Fig.2 is almost dependent on that of 2[dB] in the broadband noise between 600-1000[Hz].

Numerical simulation results

In order to clarify the mechanism of noise reduction due to tip-groove, the effect of tip-groove on the stagnation condition around the LSD blade leading edge and the secondary flow formed additionally by the tip-groove were simulated numerically. The following numerical calculation was conducted at the small flow rate of ϕ=0.13.

Figure 4 shows a comparison of the pressure recovery C_{PR} in the diffuser. The diffuser performance was deteriorated in the case with the both tip-grooves. On the other hand, in the case with the shroud tip-groove alone, the pressure recovery was almost equal to the one in the case without tip-groove. This variation of diffuser performance is quantitatively identical to the experimental results shown in Fig.2. Figure 5 shows a comparison of the lift coefficient of the LSD blade in the three cases with and without tip-groove. The abscissa is the attack angle calculated from the flow rate and the velocity triangle at the impeller exit. In the case with the both tip-grooves,

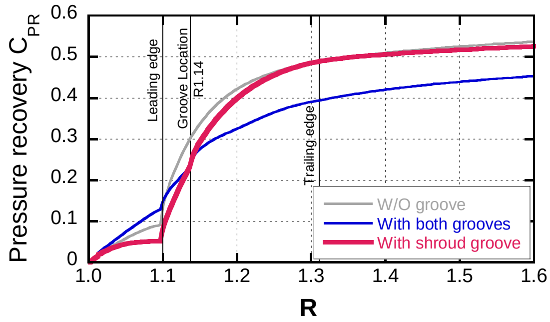


Fig.4 Comparison of pressure recovery in diffuser (ϕ=0.13)

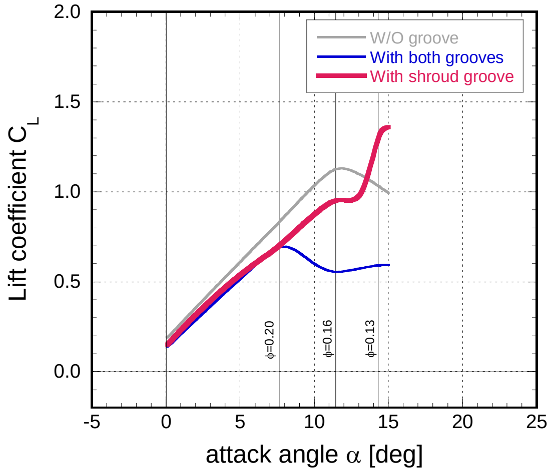


Fig.5 Comparison of lift coefficient of the LSD blade

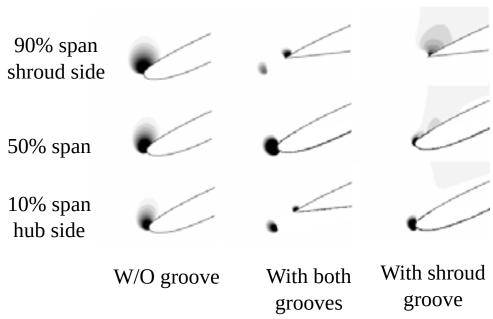
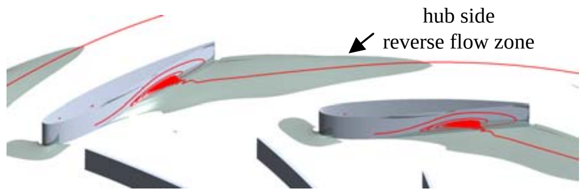


Fig.6 Comparison of high pressure region around LSD blade leading edge between the cases with and without tip-groove (ϕ=0.13)

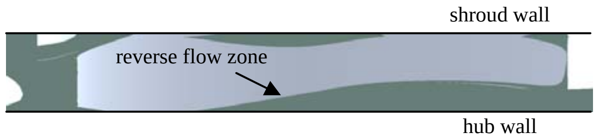
the lift coefficient decreases remarkably at the attack angle larger than 8[deg]. This is due to the large reverse flow zone formed on the suction surface of the LSD blade, as will be shown in Fig.8(b) later. In the case with the shroud tip-groove alone, on the other hand, the lift coefficient increases even at the attack angle of 14[deg] corresponding to ϕ=0.13. The higher blade loading results in the higher noise, however, it is noticed that a remarkable noise reduction was achieved as shown in Figs. 2 and 3 in the case with the shroud tip-groove alone.

Figure 6 shows a comparison of the high pressure area around the LSD blade leading edge, in other words, the stagnation condition region. In the case with the both tip-grooves, in comparison with the case without tip-groove, the stagnation region becomes smaller at 90 and 10% span locations due to tip-groove but it is little influenced at the mid-span. On the other hand, in the case with the shroud tip-groove alone, the stagnation region becomes significantly smaller in the whole span location. This decrease in stagnation region is the reason why the discrete noise of the BPF was decreased markedly. According to the reduction in stagnation region, the jet-wake interaction becomes smaller, and the pressure fluctuation on the LSD blade surfaces near the LSD blade leading edge becomes also smaller, then, not only the BPF noise but also the broadband noise must decrease.

Figures 7, 8 and 9 show the reverse flow zone and 3D streamlines around the LSD blade in the three cases respectively; Fig.7 shows the case without tip-groove, Fig.8 shows the case with the both tip-grooves and Fig.9 shows the case with the shroud tip-groove alone.; (a) shows the view from the shroud side and (b) shows the view on the suction surface of the LSD blade. In the case with the both tip-grooves, the reverse flow zone on the LSD blade suction surface is larger than the one in the case without tip-groove. This is the reason why the pressure recovery was deteriorated in the case with the both side tip-grooves. In the cases shown in both Figs. 7(a) and 8(a), the streamlines in the reverse flow zone flows downstream from the suction surface of the LSD blade along the hub wall. On the other hand, in the case with the shroud tip-groove alone shown in Fig.9(a), the streamlines from the suction surface forms the circumferentially recirculating secondary flow. This means that the high pressure recovery was achieved because the low energy fluid was swept up to the shroud wall by the secondary flow formed along the shroud wall toward the neighboring LSD blade leading edge.

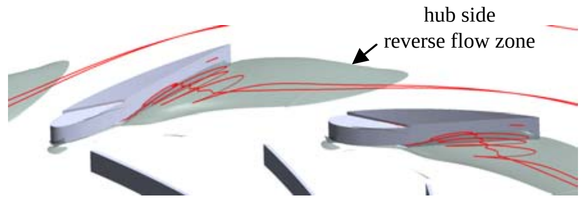


(a) On the side walls

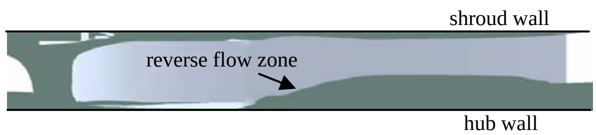


(b) On the LSD blade suction surface

Fig.7 Reverse flow zone (without groove, ϕ=0.13)

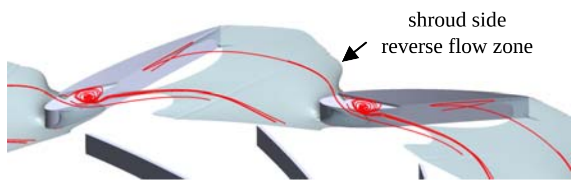


(a) On the side walls

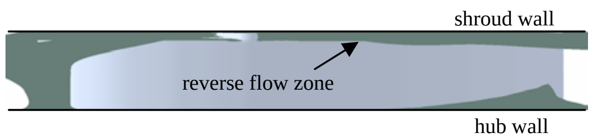


(b) On the LSD blade suction surface

Fig.8 Reverse flow zone (with both grooves, ϕ=0.13)



(a) On the side walls



(b) On the LSD blade suction surface

Fig.9 Reverse flow zone (with shroud groove, ϕ=0.13)

Conclusions

The present paper shows the effect of the tip-groove located at the LSD blade leading edge on the blower characteristics and the noise generated by the LSD. Analyzing the flow behaviors in the LSD in view points of flow separation on the suction surface of the LSD blade and the secondary flow on the side walls, the following concluding remarks are obtained.

(1) By setting up a small groove only at the shroud side

of the LSD blade tip, the stagnation region can be reduced remarkably around the LSD blade leading edge, and results in noise reduction.

(2) The secondary flow around the LSD blade is changed remarkably by a small tip-groove, resulting in the changes in noise and blower characteristics.

(3) The low energy fluid on the suction surface of the LSD blade is swept up to the shroud wall by the secondary flow formed along the shroud wall toward the impeller exit through the neighboring LSD blade leading edge.

(4) The formation of the circumferentially recirculating secondary flow is the reason why the LSD can maintain the high diffuser performance in the wide flow range without stall and the broadband noise due to the LSD can be reduced.

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