13th Australasian Fluid Mechanics Conference
Monash University, Melbourne, Australia
13-18 December 1998

Stability Improvement of a Mixed-flow Fan through the Application of Guide Fence in the Curved Vaneless Diffuser

K.Suzuki , H.Kato , S.Sato and T.Sakai
Science University of Tokyo
1-3, Kagurazaka, Shinjuku-ku, Tokyo 162-8601 JAPAN
A.Whitfield
University of Bath
Claverton Down, Bath BA2 7AY U.K.

ABSTRACT

Stability improvement of a mixed-flow fan through the application of guide fences in the curved vaneless diffuser was studied experimentally. The guide fences, which were designed with a 30 deg constant angle spiral, were attached to the hub surface and extended across the flow passage to the shroud surface by approximately 1/5 of the total passage depth. By comparison of the total performance, internal flow and rotating stall in the fan with and without the guide fences, the effectiveness of the guide fences was established. By the attachment of the guide fences, the flow structure in the diffuser and impeller was improved and the incipiency of rotating stall in the impeller was shifted to a reduced flow rate, and stall occurred over a smaller flow range.

INTRODUCTION

In the conical annular vaneless diffuser for mixed-flow machines the swirling flow, and the resultant body force normal to the diffuser walls, produces a static pressure near the hub side wall which tends to be lower than that on the shroud side wall. This, together with wall friction, leads to the development of a low energy region near the hub side wall, and flow reversal is liable to occur on the hub side of the diffuser. This unfavorable flow causes poor diffuser performance and unstable flow, such as rotating stall, in the impeller and diffuser. The reversed flow region in the diffuser creates a blockage at impeller exit and can lead to the premature onset of impeller inlet rotating stall. To rectify this unfavorable diffuser flow, Konishi et al.(1) investigated conical annular diffusers with low height guide fences attached to the diffuser hub wall. This investigation showed that the application of guide fences was effective in suppressing the development of flow reversals. Another method to rectify this unfavorable diffuser flow is the use of radially curved diffusers(2),(3). In the radially curved diffuser a body force F_r, which is generated by the curvature of meridional section, acts in the direction opposite to the body force $F_{sw}\cos\alpha$ caused by the swirling flow, see Fig.1. These body forces can cancel each other, but this is limited to the design flow rate of the diffuser only. Even with the use of a radially curved diffuser, flow reversal near the hub wall can occur at flow rates less than that at design. This reverse flow region in the diffuser becomes a blockage of impeller exit flow and brings about an unfavorable flow in the impeller.

The present experimental investigation was designed to study the effect of guide fences on the stability of a mixed-flow fan. The results show that the attachment of the guide fences on the hub side of a curved annular diffuser suppressed the flow reversal on the hub wall to reduced flow rates. This improvement of the diffuser flow reduced the discharge blockage of the upstream impeller exit flow and the incipiency of rotating stall in the impeller was suppressed to reduced flow rates. The flow range over which stall occurred was also reduced.

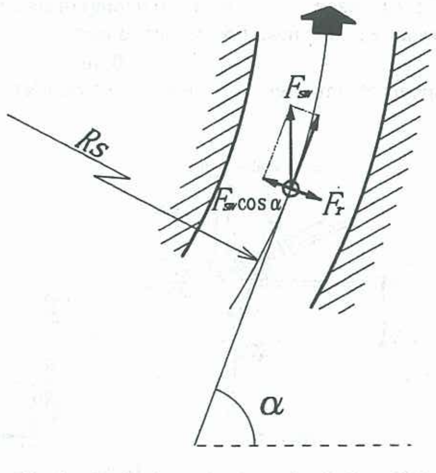

Fig.1 Body force in the mixed flow diffuser

NOTATION

c	absolute velocity (m)	
u	tip speed of impeller (m/s)	
R	radius (m)	
N	rotational speed of impeller (rads/s)	
Q	volume flow rate (m^3/min)	
p	fan pressure (Pa)	
ρ	inlet air density (kg/m^3)	
N_s	specific speed (rads)	$N_s = N\sqrt{Q}/(p/\rho)^{3/4}$
f	rotational frequency of stall (Hz)	
f_0	rotational frequency of impeller	f_0=16.67(Hz)
c_m	meridional component of velocity (m/s)	
c_θ	tangential component of velocity (m/s)	
ϕ	flow coefficient	$\phi = c_{m2}/u_2$
ψ_i	pressure coefficient of impeller	$\psi_i = (p_2-p_1)/(\rho u_2^2)$
ψ_{st}	pressure coefficient of stage	$\psi_{st} = (p_3-p_1)/(\rho u_2^2)$
β	impeller blade angle from the tangential direction (deg)	
θ	impeller inlet flow angle from the tangential direction (deg)	
R_s	radius of curvature of stream line on the meridional plane	
F_{sw}	body force due to swirl	$F_{sw} = c_\theta^2/r$
F_r	body force due to wall curvature	$F_r = c_m^2/R_s$

SUBSCRIPTS

1	impeller inlet
2	impeller exit
3	diffuser exit

APPARATUS AND INSTRUMENTION

The experimental test facilities are shown in Fig 2.For this investigation a mixed-flow fan with a specific speed of N_s=0.96 was used together with curved annular diffuser. The specification of the impeller and the diffuser was as follows:

Cone angle of impeller exit hub wall	α_2=120deg.
Impeller inlet angle	β_1=40deg.
Impeller outlet angle	β_2=60deg.
Number of blades	z=12
Mean radius of impeller exit	r_2=0.10m
Mean radius of diffuser exit	r_3=0.25m
Depth of diffuser passage	b_2=b_3=0.026m(constant)
Radius of curvature at the mean line of curved part	Rsm=0.03m
Rotational speed of impeller	N=104.72(rads/s)

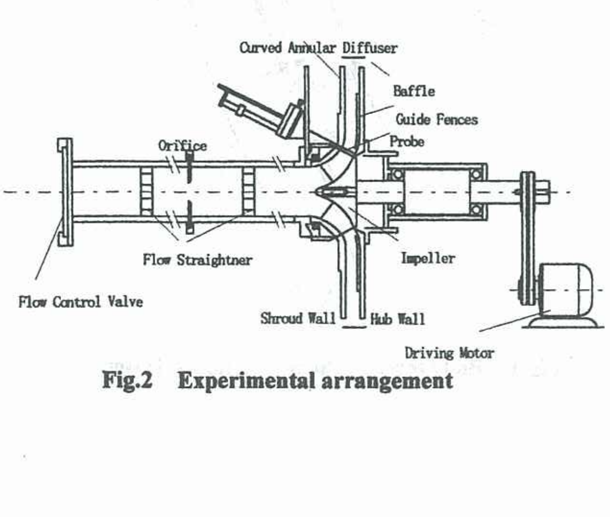

Fig.2 Experimental arrangement

The guide fences were designed with a 30 deg constant angle spiral on the developed surface of the cone, and a height of 5mm (about 1/5 of the diffuser passage depth). Eleven guide fences were placed on the hub wall of the curved diffuser from an inlet radius ratio of 1.05 to an exit radius ratio of 2.0.

The pressure fluctuations of rotating stall were detected by pressure transducers at the impeller inlet and at two stations in the diffuser, 90 deg apart, and at a radius ratio R/R_2=1.275. Precise flow measurement at the impeller inlet and in the diffuser were made. The stations for the diffuser flow measurements are shown in Fig 3. The flow distribution at impeller inlet and throughout the diffuser were measured with a three hole cobra probe which was made from 0.7mm stainless steel tubes. The maximum projected area of this probe was approximately 0.3 percent of the passage flow area and the influence of the probe on the flow field was considered to be small.

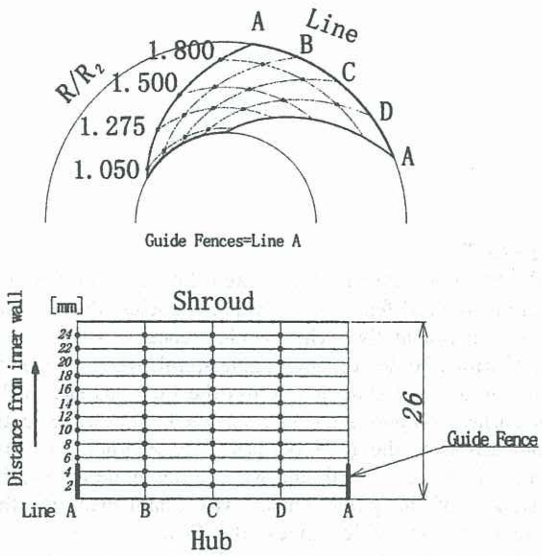

Fig.3 Internal flow measurement stations

RESULTS

1. Fan performance improvement through the application of guide fences

The basic performance of the fan with and without guide fences is shown in Fig.4. In this figure the region of rotating stall detected by pressure transducers which were installed in the diffuser is also shown. For the pressure coefficient of the impeller ψ_i, it can be seen that the inclusion of the guide fences in the diffuser influenced the impeller flow conditions and shifted the peak pressure coefficient to a reduced flow coefficient of approximately ϕ = 0.24. The domain of positive pressure gradient and the point of incipiency of impeller rotating stall were both moved towards reduced flow rates. The region over which impeller rotating stall occurred was also reduced by the introduction of the guide fences. For flow coefficients larger than ϕ = 0.28 the impeller pressure coefficients with and without the guide fences were very similar. The pressure coefficient for the complete stage, ψ_{st} was, however, improved by the introduction of the guide fences in spite of the different incidence angles which occur for high and low flow rates. This improvement in stage performance is due to improved diffuser performance through the introduction of the guide fences.

2. Improvement of flow in the diffuser and impeller

The distribution of the meridional component of velocity at the impeller inlet and through the diffuser, measured by a three hole cobra type yaw probe, is shown in Fig.5.

For the diffuser without guide fences the flow deviates towards the hub wall at $\phi = 0.32$ and towards the shroud wall at $\phi = 0.25$. From these flow patterns it can deduced that the most favorable flow pattern in the curved diffuser occurred at flow coefficients between $\phi = 0.25$ and $\phi = 0.32$. A one dimensional flow analysis of the fenceless diffuser showed that the body forces Fr and Fsw sinα in the curved portion of diffuser, and near the hub wall, were in balance at a flow coefficient ϕ of approximately 0.29. Through the application of the guide fences the flow deviation from hub to shroud was rectified and flow reversals, which are seen with the diffuser without fences, were eliminated.

At the low flow coefficient, $\phi = 0.21$, the introduction of the guide fences rectified the reverse flow on the hub wall at diffuser inlet; however, the distribution of the meridional component of velocity at diffuser discharge became unfavorable, with a low velocity on the hub and the flow skewed towards the shroud surface.

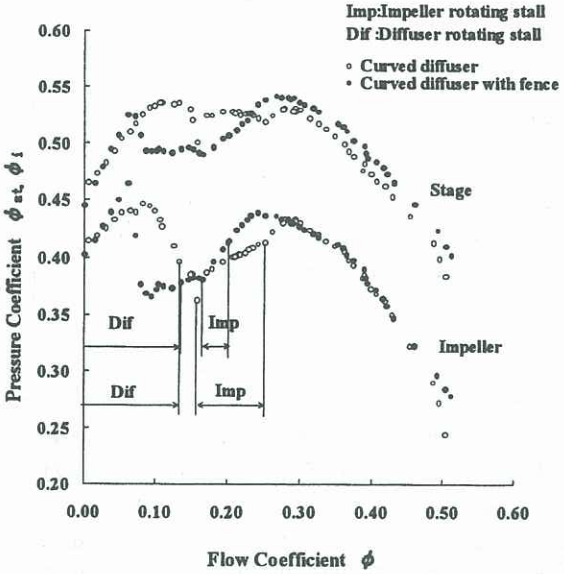

Fig.4 Pressure coefficient of impeller

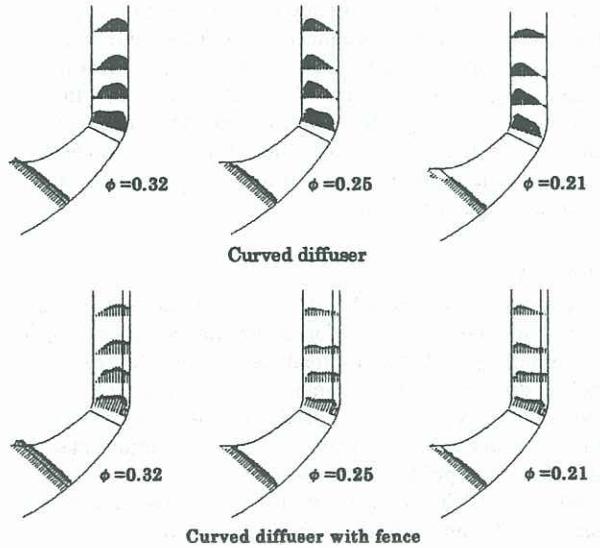

Fig.5 Distributions of meridional velocity

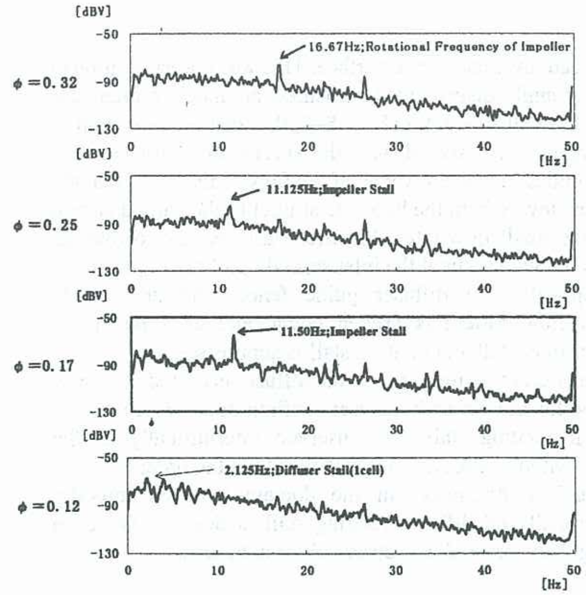

Fig.6-1 Spectrum of pressure fluctuations (For Curved diffuser)

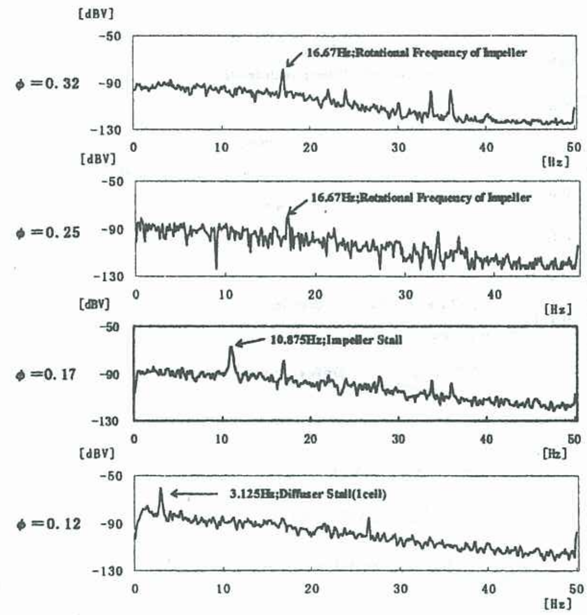

Fig.6-2 Spectrum of pressure fluctuations (For Curved diffuser with fence)

3. Impeller and diffuser rotating stall

The frequency spectra of diffuser pressure fluctuations for both diffuser configurations are shown in Figs.6.1 and 6.2. Rotating stall in the impeller and diffuser were clearly discerned by the frequency of rotating stall. The rotational frequency of the impeller and diffuser stall, normalized by the impeller rotating frequency, is shown in Fig.7. This clearly illustrates, for the diffuser with guide fences, a distinct increase in the stall frequency as the flow coefficient was reduced, this is particularly apparent for the impeller stall. By the application of diffuser guide fences the point of inception of rotating stall in the impeller was shifted from $\phi = 0.25$ to $\phi = 0.21$ and the flow region over which impeller rotating stall occurred was reduced.

From Fig.5 it can be seen, for the diffuser without fences, that flow reversals developed on the hub wall when the fan was operated in the low flow region. Due to the blockage caused by this reverse flow, the impeller discharge flow was forced towards the shroud side. At impeller inlet, however, the flow was forced towards the hub surface. This was observed through the flow angle distributions measured at impeller inlet, see Fig.8. At small flow rates (Figs. 8–2,3), a distinct reduction in flow angle was observed near the shroud tip, with negative angles indicating local reversal of the flow. This shows that the impeller flow is from the hub side at inlet to the shroud side at outlet for small flow rates. Impeller stall, leading to rotating stall, is liable to occur at the inlet shroud tip of the impeller. By the application of diffuser guide fences the unfavorable diffuser flow pattern is broken down, and as a result the impeller inlet stall and rotating stall is suppressed.

The onset of rotating stall in the diffuser occurred at similar flow coefficients for both diffuser configurations. A single and two cell rotating stall was observed intermittently in the diffuser without fence at flow coefficients of the order of 0.1, see Fig.7. Furthermore, in the domain between impeller rotating stall and diffuser rotating stall, a domain where no rotating stall occurred was observed for both fans.

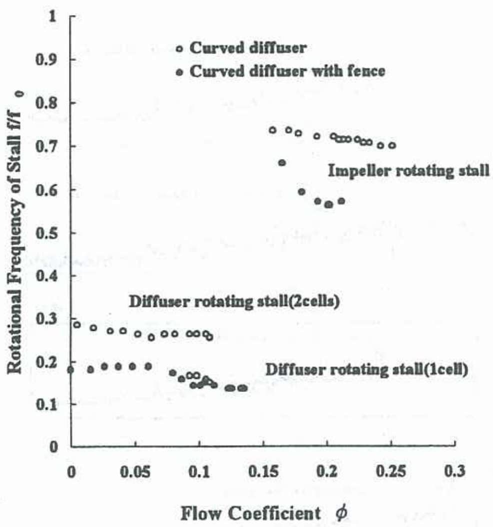

Fig.7 Rotational frequency of stall

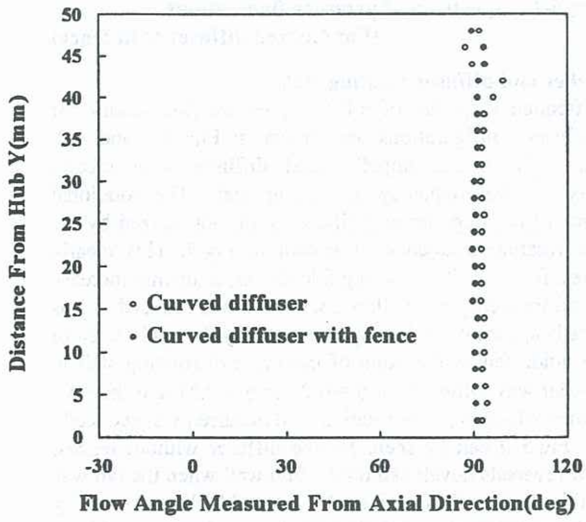

Fig.8-1 Flow angle of impeller inlet at ϕ=0.32

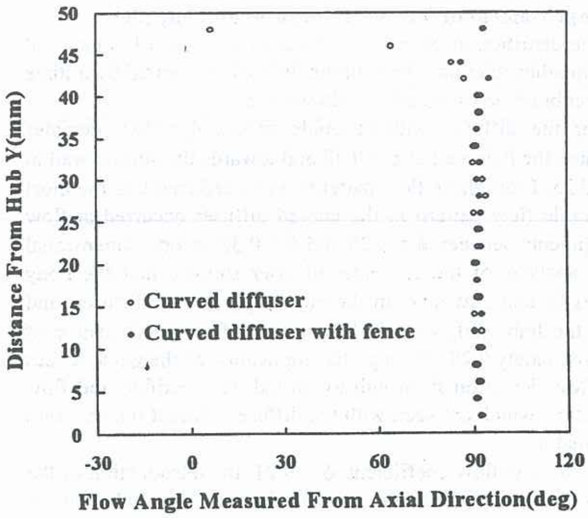

Fig.8-2 Flow angle of impeller inlet at ϕ=0.25

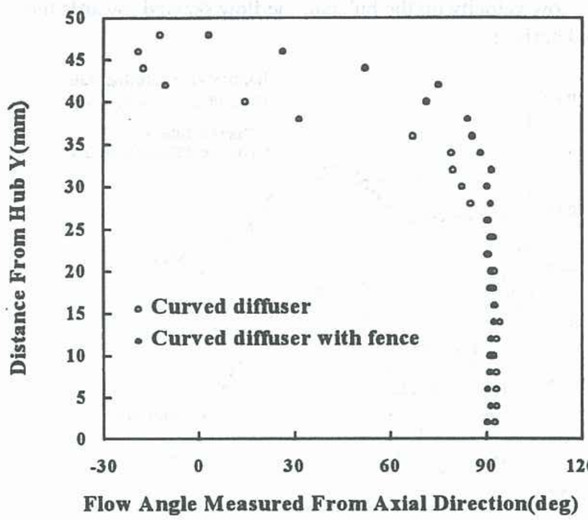

Fig.8-3 Flow angle of impeller inlet at ϕ=0.21

CONCLUSIONS

By the attachment of the guide fences to the hub side of the diffuser the flow structure in the diffuser and the impeller of the mixed flow fan was improved. As a consequence the point of incipiency of rotating stall in the impeller was shifted to a reduced flow rate, and stall occurred over a reduced flow range. The overall improvement of the diffuser flow structure by the introduction of the guide fences led to enhanced performance of the fan across the full flow range. Suppression of the impeller stall led to an improvement in the operating range of the fan.

REFERENCES

(1) T.Konishi,T.Sakai and A Whitfield Installation effect in fan systems pp37-53 Performance improvement of mixed-flow fan through the application of guide fences in the vaneless diffuser IMechE Seminar Publication1997

(2) Y.Niizeki,T.Sakai et.al A Study of Radially Curved Mixed-Flow Vaneless Diffusers JSME International Journal Vol 31,No2 pp252-257 1994

(3) A.Yadoiwa, A.Whitfield T.Sakai et.al Rotating Stall in Mixed-Flow Turbomachines Proc. of 12th AFMC Vol.1 pp69-72 1995