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Flow in Axial Blade*

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The flow behaviours of the flow field in a impeller and guide vane of axial blower have been observed using the technique of visualization by silk tufts. When the stall zone is limited to the tip region only, the surging zone on the ψ - ϕ characteristics does not appear clearly. Therefore, if the suction or delivery concentric rings have the effect to prevent the stall zone from extending toward the section within geometrical mean radius, the stall characteristics of an axial machine will be improved.

In the stationary guide vane of an axial blower, the blade characteristics are better than those of other section, owing to the flow in the boundary layer from tip to root caused by a secondary flow in the curved channel.

Introduction

In this paper, the author describes the flow behaviour in an axial impeller and guide vane of a retarded flow free from cavitation. It is desirable that cavitation does not occur in the nominal point of hydraulic machine. And in the cavitationless flow condition, a fluid flow in the axial pump is same as that in the axial blower if the compressibility of air is neglected, because Reynolds number and the blade design theory are nearly the same between pump and blower.

The author advises use of air to observe the flow behaviours in the impeller, guide vane and other parts of hydraulic pump, because air is more convenient to treat, to photograph and to make fine observation than water. Therefore in the following description, research results on one stage axial blower are stated. Further, he describes the flow condition in an axial impeller and guide vane at running state but not the flow behaviour in a two-dimensional cascade.

Nomenclature

The following nomenclature is used in the paper.

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c_a : axial velocity

c_L : lift coefficient

l : chord length

r : radius

t : pitch of blade

u : peripheral velocity

α : angle of attack

ϕ : flow coefficient c_a/u

ψ : pressure coefficient, $P_t / \frac{\gamma}{2g} u_t^2$

γ : specific weight of fluid

subscript t : blade tip

Other symbols are illustrated in the Figures.

1. Flow in axial impeller

The peripheral velocity of one stage axial blower is at most about twice or thrice as large as that of one stage axial pump. But Reynolds number of impellers of axial blower and pump at running state are almost of same order which is limited to about $10^4 \sim 10^6$. The work to be reported here involves the investigations of the detailed visualized flow behaviours in the different axial blades. Fig.1 is the dimensionless characteristics of one stage axial blower of axial inlet type with 320 mm diameter and 0.5 hub ratio.

Fig.2 is the behaviours of a flow in the

impeller of one stage axial blower visualized by silk tufts which are stretched at the inlet and outlet of the impeller. These Figures are photographed using micro-flash at 1/500 000 sec of exposure. Flow rate (3) shown in Fig.1 is in the vicinity of maximum efficiency and an approximately perfect two-dimensional flow is observed, except the slight outward flow in tip region of outlet. At

Fig. 1 Dimensionless characteristics of axial inlet type blower with 320 mm diameter. No. in parentheses corresponds to flow rate in Fig. 2

Fig. 2 Visualized flow behaviour by silk tufts in the impeller of axial blower

flow rate of maximum pressure, flow disturbance occurs at the blade tip both of entrance and exit of impeller. This is caused by leakage from the tip clearance and partial stall of the blade tip. Visual observation also indicates that more severe disturbances can exist in the stall region of flow rate (6). When a reversed flow due to stall extends near the geometrical mean radius, a depression on the pressure-capacity characteristic curve appears clearly. In the stall region, it is impossible to obtain clear photographs by the technique of smoke flow visualization. In the perfect stall region of small flow rate (8) of Fig.1, the flow behaviour in the impeller becomes outward radially three-dimensional in all regions.

It is predicted that the stall characteristics of a blower will be improved by localizing the blade stall region which occurs due to the increased stalling attack angle resulting from leakage from tip clearance and retarded flow in the boundary layer on casing wall. To prove this fact, a characteristic test has been carried out using concentric rings which are put extremely close to blade, to prevent the stall region from extending into the radius within geometrical mean section. Fig.3 is the test installation used for the test of suction and delivery concentric rings. Fig.4 is the comparison of characteristics of axial blower with suction or

R: impeller, G: guide vane after impeller
Fig. 3 Arrangement and nomenclature of suction and delivery rings

Fig. 4 Comparison of dimensionless characteristics of axial blower with or without suction and delivery ring

delivery ring only or both concentric rings. From this Figure, it is clarified that the stall characteristics are improved remarkably. The effect of suction concentric ring to prevent the stall is clarified by the visualized flow behaviours shown in Fig. 5, which are photographed by the same technique as in Fig. 2. The reverse zone is limited merely to the outer region of plastic suction ring, even when a severe stall occurs without a suction ring. The effects of ring diameter, ring length and axial clearance between ring and blade on the characteristics of blower are investigated. It is

found from the experimental results that the ratio of radial clearance c_r to blade span S should be about 0.17 and axial clearance c_a should be small as possible and the axial lengths of rings l_s and l_o are desirably equal to about $(1.5 \sim 2) S$.

Subsequently, the flow condition in the impeller of an axial blower which has no remarkable stall characteristics, is investigated. Fig. 6 is the dimensionless characteristics of one stage axial outlet blower with 380 mm diameter and 0.5 hub ratio. Visualized behaviours of flow in the impeller corresponding to the flow rates denoted by the

Fig. 5 Visualized flow behaviours in the axial impeller with suction ring

Fig. 6 Dimensionless characteristics of axial blower of axial outlet type with 380 mm diameter

Fig. 7 Visualized flow behaviour in the impeller of axial outlet type (see Fig. 6)

numbers in parentheses on the ψ - ϕ characteristic curve of Fig.6, are shown in Fig.7. From these photographs, it is found that the flow condition before the pre-stator are nearly two-dimensional, even if the flow rate decreases extremely. Though fairly severe disturbances exist at the tip of blade inlet, a depression on ψ - ϕ characteristic curve due to stall does not appear clearly. At flow rate (5) of Fig.7, there is no severe reverse flow at the inlet of impeller, though the flow is disturbed extremely at the inlet.

The reason of the above mentioned fact is not clarified from the test results on the effect of concentric rings and visualized flow behaviour, but if the flow disturbance is limited only to either of the inlet or exit of impeller tip region, there will be no severe stall zone on the characteristic curve. And if flow disturbances occur at both inlet and exit of impeller, a depression due to stall appears clearly on the characteristic curve of blower. In the case of Fig.6, the stall characteristics are improved by inserting the concentric

suction ring, which limit the flow disturbance at flow rate (5) or (7), shown in Fig.7, to the tip region of blade. Because in this case no flow disturbance in the impeller at flow rate (5) or (7) exists at the outlet from the first, the delivery ring has no effect to prevent stalling. The performance of blower at large flow rate becomes worse due to the increasing fluid resistance owing to rings.

2. Flow behaviour in suction and delivery pipes

Figs.8 and 9 are the visualized flow conditions corresponding to the characteristics of Fig.1 in the suction and delivery pipes which are away from the impeller and guide vane. In the suction pipe shown in Fig.8, the reverse flow is limited to the vicinity of impeller even if partial stall cells exist in the impeller. Perfect reversed flow extending to the inlet of suction pipe occurs first at an approximately zero flow rate. Air flows into the suction pipe from the center parts of pipe and flows upstream from casing wall side. Fig.9 is the flow conditions in the delivery pipe. It is surmised that the flow behaviour slightly apart from the outlet guide vane is nearly two-dimensional even if the flow rate of blower is very small. Namely the reverse flow region at the exit of impeller is limited to the vicinity of impeller and guide vane, as compared with the case of inlet pipe.

3. Flow behaviour in axial guide vane

Detailed nature of the flow field in a retarded guide vane which is behind the impeller is investigated here. The guide vane used for the research is the circular arc profile made of a steel plate of 0.8 mm thickness. There are 10 blades. Main symbols and dimensions are shown in Fig.10 and Table 1. In the single stage axial machines, it is usual for the design of guide vane of circular profile to use the stream line theory rather than the aerofoil theory. The values of designing excess angles which are the differences between blade angles and actual flow angles, at the inlet and outlet of this guide vane, are 5° uniformly. In the guide vane, the flow conditions differ considerably

Fig. 8 Flow behaviours in the suction pipe, corresponding to the characteristics of Fig. 1

Fig. 9 Flow behaviours in the delivery pipe, see Figs. 1 and 8

(a) Velocity diagrams

(b) Sections of measurement

Fig. 10 Symbols and nomenclatures in guide vane after impeller, see Table 1

Table 1 Dimensions of circular arc guide vane for the test.
Nomenclatures are shown in Fig. 10. unit:mm

Section	r	l	t	t/l	f/l	a	r_g	e	θ°	τ_3^{*0}	τ_4^{*0}
t	300	148.8	188.0	1.26	0.079	151.3	240.8	145	77.0	59	95
1	289	149.1	181.5	1.22	0.082	151.7	235.0	145	76.5	58	95
2	267	149.8	167.3	1.12	0.086	152.7	224.3	145	75.5	56	95
3	244	150.5	153.3	1.02	0.091	153.7	214.8	145	74.5	54	95
4	217	151.6	136.3	0.90	0.098	155.4	202.4	145	73.0	51	95
5	191	153.4	119.7	0.78	0.106	157.9	188.5	145	71.0	47	95
r	180	153.8	112.8	0.73	0.109	158.6	185.5	145	70.5	46	95

from point to point in one pitch, owing to the boundary layer on the blade surface, casing wall and hub and the secondary flow in the guide vane. Assuming that the inlet flow behaviour of guide vane is same as that of outlet of impeller, the flow conditions at the exit of guide vane are measured at 20 points, which are distributed at 5 sections of radial direction and 4 sections of peripheral direction, using the three-hole yaw probes of 4 mm diameter. Measuring points 1-1~1-5 are on the pressure side and 4-1~4-5 are on the suction side, as shown in Fig. 11. These points are apart 10 mm inside and downstream from the trailing edge of blade respectively.

3.1 Axial velocity distribution

Axial velocity distributions at the inlet and outlet of impeller or guide vane are given in Fig. 12 (a) and (b). On the mean radius at nominal point, the axial velocity at the inlet of impeller is same as that of the outlet of guide vane. It seems that the wake flowing out of the impeller does not vanish even after passing through a guide vane. Estimating from the axial velocity distribution at the outlet of guide vane, a three-dimensional flow becomes severe as a result of the deflection of flow. Generally speaking, axial velocity at the outlet of guide vane is small at the blade tip and large on the hub owing to the separation of boundary layer of impeller.

3.2 Blade characteristics of guide vane

Fig. 11 Measuring points at the outlet of circular arc guide vane of axial inlet type (see Table 1)

Characteristics of blade element on the tip, mean and root radius calculated from velocity and its direction measured by using three-hole probes are shown in Fig. 13 (a), (b) and (c). Because the flow behaviour varies with the peripheral positions, the blade characteristics calculated from these values are naturally different. At the tip of stationary guide vane, the blade does not stall at a considerable large attack angle and the lift coefficient is larger than that of mean or root radius. As shown in Fig. 11, due to the flow denoted by arrows from tip to root resulting from the secondary flow in the boundary layer of guide vane, the boundary layer thickness becomes thin at tip of stationary guide vane. Therefore, for the above

reason, in addition to the small blade interference effect due to small solidity, the stationary blade tip section has good characteristics. Ratio of the measured lift coefficient to the theoretical value calculated from design data is 0.94. At the tip of guide vane, a secondary flow has, as stated above, favourable effect on blade characteristics.

The stationary guide vane after impeller is to vary the whirl velocity energy to effective

static pressure and to obtain uniform total and static pressure distribution at the outlet of guide vane. From the experimental results, it is found that the static pressure increases slightly toward the outer casing, and its behaviour does not vary with decreasing flow rate. Total pressure is small like axial velocity at tip and root of guide vane. It is found that the design method to obtain uniform axial velocity at the impeller is important

(a) Axial velocity distributions at nominal flow rate, $\phi=0.312$

(b) Axial velocity distributions at max. pressure, $\phi=0.248$

Fig. 12 Axial velocity distributions

(a) Section 1 (tip)

(b) Section 3 (geom. mean)

(c) Section 5 (root)

○ ; 1-1, ● ; 2-1, ⊗ ; 3-1, ⊙ ; 4-1

Fig. 13 Characteristics of blade element of guide vane

to get good blade characteristics of a stationary vane after the impeller.

Conclusion

(1) Stall on the pressure-flow rate characteristic curve occurs due to the flow disturbance at both inlet and outlet of the impeller, resulting from a reverse flow and stalling of blade element.

(2) Even if the blade tip does stall, when its effect is limited to the tip region only, the characteristics of the axial blower will be good.

(3) In the guide vane after the impeller, the flow behaviour is different from point to point in one pitch and the deformation of velocity profile at the exit of impeller does not vanish easily.

(4) When a guide vane is assumed as a curved channel, a secondary flow from tip to root occurs on the boundary layer of the stationary guide vane. And the blade characteristics will be better than those of other sections.

(5) Some remaining whirl at the outlet of guide vane has no harmful effect on the efficiency of blower. Static pressure increases toward the blade tip but the main factor for uniformity of total pressure distribution is deformation of velocity profile.

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