Study on the Fluctuating Flow in an Axial Flow Fan (Effects of Operational Conditions and Rotational Speeds)

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Fluctuating flow in the three various operating conditions on the normal operating range of the flow characteristic curve in the single stage axial flow fan with stationary blade ahead of fan wheel is treated in this paper. The fluctuating three dimensional flow in the moving blade passage is measured using a hot wire probe. Measurements are made four times at the same measuring position by inserting the probe in the different holes of the probe support. The probe is rotating with the moving blade and traversed. The passage of wake of the upstream stationary blade and the periodic fluctuating flow, arising from the relative movements, are observed. The characteristics of the leakage flow from the blade tip are discussed. These characteristics of the leakage flow from the blade tip are discussed. These phenomena are treated for various operational conditions and rotational speeds.

Keywords: Axial flow fan; Fluctuating flow; Measurement of flow; Flow in the moving blade passage

1. EXPERIMENTAL APPARATUS AND METHOD

1.1. Experimental Apparatus

The specifications and main dimensions of the single stage axial flow fan used for this research are shown in Table I. The flow pattern of the fan is a free vortex type and its type number is 2.06. Measurements of the fluctuating flow in the moving blade passage are made at three points under normal operating conditions of the characteristic curve, as shown in Figure 2, i.e., *FP1*, *FP2* and *FP3*. Rotational

speeds are 600, 1500, and 2400 rpm. Here, 600 rpm corresponds to the laminar flow range, 1500 rpm to the transitional flow range, and 2400 rpm to the turbulent flow range, respectively (Adachi et al., 1998). The tip clearance between the inner wall of the casing and the blade tip of the moving blade is 0.8 mm.

A hot wire probe, as shown in Figure 1, is used to measure the direction and magnitude of the flow. The hot wire probe is inserted in the radial and circumferential direction by using two inserting holes. In the radial and circumferential direction, there are two ways to insert the hot wire probe using these two holes, respectively. Then, the measurements are made 4 times at the same measuring positions. To traverse the hot wire probe in the blade passage while it is rotating, a traversing apparatus is used. The apparatus is rotated with the moving blade. When the stepping motor is made to rotate during the rotation of the shaft, the main body rotated relative to the shaft. The angle of rotation is 0.135° per each step of the stepping motor. The feed current to the stepping motor and the out put signals from the hot wire probe are received through the slip ring attached to one end of the shaft.

1.2. The Method of Measurement

The measuring positions in the moving blade passage are as shown in Figures 3a and b. In the axial direction, the leading and the trailing edge of the hub is designated by $Z=0$ and 1.0, respectively. Dividing the axial distance between these two points by 5, six axial positions, i.e., $Z=0$, 0.2, 0.4, 0.6, 0.8, and 1.0, are obtained. In the radial direction, 11 measuring positions are taken. The position is designated by H . In the circumferential direction, the origin is taken at the trailing edge of the hub. The numbers of measuring positions are 9 to 18 points, depending on the axial- and radial position of measurement. The hot wire

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TABLE I Specification and main dimensions of the fan used in this research

Discharge coefficient	0.507
Pressure coefficient	0.550
Type number	2.06
No. of revolution	300 ~ 3000 rpm
No. of stationary blades	13
No. of moving blades	10
Outer diameter	0.5 m
Hub ratio	0.6
Flow pattern	Free vortex type

FIGURE 1 Hot wire probe and its support.

FIGURE 2 Pressure and discharge curve.

FIGURE 3a Measuring positions in the radial and axial direction.

FIGURE 3b Measuring positions in the radial and circumferential direction.

FIGURE 4 Relative positions of stationary and moving blade at the start of measurements.

probe is inserted into the upstream direction. As the moving blade passage is distorted, there are more positions where the hot wire probe can not be inserted. The measuring positions in the radial and circumferential direction at $Z = 1.0$ was shown in Figure 3b.

Measurements are started at the instant when the trailing edge of the fixed moving blade is in the downstream of the trailing edge of the stationary blade, as shown in Figure 4. The sampling periods are 0.5 ms for 600 rpm, 0.2 ms for 1500 rpm, and 0.12 ms for 2400 rpm. Sixty measurements are made at these time intervals. Then the measuring positions cover one third of every rotation. These samplings are repeated and every data are summed up 2^9 times in order to eliminate the random components. The magnitude and direction of velocity at every instant are calculated by these 4 signals measured at the same measuring position. The method of calculation is described in the reference (Adachi et al., 1995). The effects of potential flow interference of these two blade rows are considered to have disappeared at these blade distances. The time period for the moving blade to pass one pitch of

the stationary blade is 7.69 ms for 600 rpm, 3.08 ms for 1500 rpm, and 1.92 ms for 2400 rpm.

2. MEASURED RESULTS FROM THE FLUCTUATING VELOCITY

2.1. Fluctuating Velocity in the $Z-\Theta$ Plane

Figures 5a–b show the fluctuating velocity components, i.e., the difference of the three components of the velocity from the time averaged value at each of the measuring positions.

These values are normalized by the averaged axial velocity component at the same radial positions. This value is shown as the unit in the figures. The arrows show the circumferential and axial components ΔV_Θ and ΔV_Z with taking the origin at the measuring positions. The solid markers $\bullet$ show the radial components ΔV_R . The radial outward velocity components are shown to be upward from the measuring positions. The clear markers $\odot$ show the minimum velocity positions in the axial direction. The markers $\triangle$, $\blacktriangle$, $\square$, $\times$, $\blacklozenge$, etc., show the positions of the trailing edges of the stationary blade at each instant, as shown in Figure 4.

FIGURE 5a Fluctuating velocity distribution in the $Z-\Theta$ plane $FP1$, $H05$, 600 rpm.

FIGURE 5b Fluctuating velocity distribution in the $Z-\Theta$ plane $FP3$, $H05$, 600 rpm.

Figure 5a shows fluctuating velocity in the moving blade passage as time progressed. It is taken near the hub, and the number of revolutions is small (600 rpm) and the operating condition is *FP1*. The wakes, which shed from the trailing edge of the upstream stationary blade, flow through the blade passage. They move across the moving blade passage as time progressed. As the flow velocity is larger along the suction side than along the pressure side of the moving blade, the trace is curved to the axial direction, as it flows downstream. As the design flow pattern of the fan is free

vortex type, the velocity defects are markedly large and radial outward flow can also be observed in the wake. Figure 5b shows the result taken at *FP3*. Comparing this figure with Figure 5a, the passage of wake have a larger angle to the moving blade chord and the trace of the wake goes through the blade passage in the axial direction. The flow disturbance which arises due to the passing wake, has some irregularities compared with Figure 5a.

Figure 6 shows the result taken at *FP1* and *H95*. It is taken near the tip. In this figure the leakage flow through the

FIGURE 6 Fluctuating velocity distribution in the $Z-\Theta$ plane *FP1*, *H95*, 1500 rpm.

FIGURE 7 Fluctuating velocity distribution in the $Z-\Theta$ plane *FP3*, *H95*, 600 rpm.

tip clearance can be observed. The disturbance from the tip clearance seems to be random at a glance but it is influenced by the position of the stationary blade. The leakage flow is remarkable at $T=0$ and 0.6 ms. It is not obvious at $T=1.2$ and 1.8 , and it becomes obvious at $T=3$ ms again. The mechanism of flow leakage through the tip clearance is as if it is forced out by the stream passage formed by the upstream stationary blade and moving blade. The leakage flow rises remarkably, when the trailing edge of the

stationary blade comes to the moving blade. Figure 7 shows the results taken at $FP3$ and $H95$. The leakage flow shows quite a random phenomena in this operating condition. The leakage rises at every instant. Figure 8 shows the result taken at the larger number of revolution, i.e., in the turbulent flow range. The irregularities prevail the total area of the moving blade passage. The irregularities prevail the total area of the moving blade passage at these operating conditions and measuring positions.

FIGURE 8 Fluctuating velocity distribution in the $Z-\Theta$ plane $FP3$, $H95$, 1500 rpm.

FIGURE 9 Fluctuating angle distributions in progress of time $FP1$, $Z = 1.0$, 600 rpm.

3. FLUCTUATING VELOCITY IN THE $R-\Theta$ PLANE

3.1. Distributions of Fluctuating Flow Angle and Dynamic Pressure in the Moving Blade Passage

The fluctuating flow angle means the difference in the angle $\tan^{-1}(V_\Theta/V_Z)$ with the mean value at the measuring

position. The fluctuating dynamic pressure means the difference in the dynamic pressure from the steady values divided by the mean dynamic pressure of the mean relative velocity value.

Figure 9 shows fluctuating angle distributions as time progress. It is taken at $FP1$ and 600 rpm. The flow angle takes the larger values in the wake regions of the upstream stationary blade. Figure 10 shows the fluctuating dynamic pressure at the same operating condition. In comparing

FIGURE 10 Fluctuating dynamic pressure distributions in progress of time $FP1$, $Z=1.0$, 600 rpm.

FIGURE 11 Fluctuating angle distributions in progress of time $FP3$, $Z=1.0$, 600 rpm.

Figures 9 and 10 at time $T=0$ and 1.5, there can be observed a radial band zone of large angle on the left side of the pressure surface of the moving blade in Figure 9. This zone corresponds to the zone of smaller dynamic pressure in Figure 10. In Figures 9–12 solid radial lines show trailing edges of upstream stationary blades. In the wake the axial component of flow velocity is smaller, and the flow angle becomes larger. At the intersecting point of this band zone with the outer casing, a zone of a smaller angle can be seen. As is explained in Figure 6, the leakage

flow increases at this instant. The small flow angle arises, as it is pushed out by the moving blade. At $T=3.0$ and 4.5 ms, this band can hardly be observed, because the wake intersect with the moving blade. At $T=6.0$ and 7.5, this zone appears again in the moving blade passage.

Figure 11 shows the fluctuating angle distribution taken at *FP3* and 600 rpm. The distribution phenomena of the flow angle is quite different from that of Figure 9. The clear band zone of the larger angle disappears and the zone of small and large flow angle mix. It is because of the flow mixed at *FP3*. Figure 12 shows the result taken at *FP3* and 2400 rpm. The mixing of the flow is more remarkable at a higher numbers of revolutions.

4. CONCLUSIONS

The flow phenomena in the $Z-\Theta$ plane

- (1) The wakes, which shed from the trailing edge of the upstream stationary blade flow through the moving blade passage. It is curved to the axial direction as it flows downstream at *FP1* and for smaller numbers of revolution. Flow disturbance, which arises due to the passing wake, have more irregularities for *FP3* at the same number of revolutions.
- (2) Near the tip the leakage flow through the tip clearance can be observed. This disturbance seems to be random at a glance, but it is influenced by the position of the stationary blade for *FP1*. For smaller flow discharge and a higher number of revolutions, the flow phenomena becomes quite random.

The flow phenomena in the $R-\Theta$ plane

The flow angle takes the larger values and fluctuating dynamic pressure takes the smaller value in the wake regions of the upstream stationary blade. At the intersecting point of this band zone with the outer casing, there can be seen a zone of smaller values of angle. This arises as if it is forced out by the stream passage formed by the upstream stationary blade and moving blade. For *FP3* and for higher numbers of revolutions, the fluctuating angle distribution phenomena show quite different. The clear band zone disappears and the zones of small and large flow angle are quite mixed.

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FIGURE 12 Fluctuating angle distributions in progress of time *FP3*, $Z=1.0$, 2400 rpm.