621.634.01:532.595

Study on the Flow Fluctuation in the Axial-Flow Fan*

(Part 1, Spectrum of the Total Pressure Fluctuation on the Flow in the Axial-Flow Fan)

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In the present paper, the spectra of total pressure fluctuation of flow for various operating conditions and measuring places are shown. They are obtained by a pick-up of condenser microphone type. These researches have brought the following conclusions:

(1) The spectrum of fluctuation consists of the following two parts:

i) The component, the frequency of which is $(NZ)/60$ c/sec or its multiples, where N is the speed of the fan per minute, Z is the number of moving blades, and ii) the component, the frequency range of which is considerably wide, and the magnitude of which is quite indefinite.

(2) The first arises from the fan wheel, the second from the disturbance of the flow around the bodies in the fan.

(3) The magnitude of the component which has the frequency of $(NZ)/60$ c/sec is proportional to the square of speed of the fan.

1. Introduction

When the blades of a fan wheel move in its casing, the static and dynamic pressures of the flow fluctuate and produce vortices in the down stream of the bodies in the fan, i.e. blades, boss etc. These are the causes of the flow fluctuation in the fan which occur under all operating conditions. Besides them, surging and rotating stalls are also considered to be the causes of the flow fluctuation in the fan. These total pressure fluctuations of the flow are causes of fan noise, fatigue failure of blades, and some secondary losses of flow in the fan.

Among these flow fluctuations, the phenomena which arise under stalled operating conditions, i.e. surging, rotating stall etc., have often been researched. As yet few investigations which deal with the fluctuation phenomena arising under unstalled operating conditions have been made, moreover these are theoretical researches. In these theoretical researches, assumptions have been made about the causes of flow fluctuation. One of them assumes vortices, and the other viscous wakes, instead of

the moving blades⁽¹⁾.

In this way the causes of these flow fluctuations have not been researched. The total pressure fluctuation that arises under unstalled operating conditions has nowadays become a very important problem.

Under these circumstances, the authors tried to explain the cause of flow fluctuation, by performing an experiment with an axial-flow fan designed for this purpose, a model experiment and theoretical calculations.

Among these, the measured results and their classifications are treated in this report.

2. Description of equipment and experimental procedure

Table 1 and Fig.1 show the specification and the chief dimensions, and Fig.2 the characteristic curve of the fan used. The experiment was also performed by inserting the duct as shown in Fig.3, between parts © and ④ in Fig.1. In this case, in giving the results of the experiment, "duct 1" is used to show the results of the case in Fig.1, and "duct 2" to show the results of the inserted duct case.

The pick-up of a condenser microphone type as shown in Fig.4 was used to measure the total pressure fluctuation. It has as shown by ② a foil

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of aluminium which is 5 mm in diameter and 0.015 mm in thickness. Change of electrostatic capacitance, produced by displacement of this foil, is amplified. Two methods are employed to measure the total pressure fluctuation. One way is method 1 (Fig. 5), and the other is method 2 (Fig.

Fig. 1 Axial-flow fan with guide vanes at back of the fan wheel

Fig. 2 Characteristic curve of the fan

Fig. 3 Inserted duct

Fig. 4 Pick-up of measuring instrument of pressure fluctuation

6). Method 1 is employed when the measuring places are far from the moving blades, and method 2 is employed when the measuring places are in the neighbourhood of the blades.

Fig. 7 shows the frequency characteristic of the measuring instrument of pressure fluctuation. When we use the pick-up in the way as shown in Fig. 6, we must measure the acoustical characteristic of this attachment. For this purpose we measured the same fluctuation phenomena of flow by these two methods, and compared the measured spectrum by method 2 with that by method 1. Then we found that there was a peak frequency of flow fluctuation at about 3 900 c/sec in measured spectrum by method 2, and that there were not any differences below 2 000 c/sec. The peak is believed to be the natural frequency of this attachment. So when we show the spectra of the total pressure

Fig. 5 How to use the pick-up (method 1)

Fig. 6 How to use the pick-up (method 2)

Fig. 7 Frequency characteristic of the measuring instrument of pressure fluctuation

Table 1 Specification and chief dimensions of the axial-flow fan

Volume of flow	195 m ³ /min	Type of fan	Single stage axial-flow fan with guide vanes in back of the fan wheel
Static pressure	50 mmAq	Profile of moving blades	Gö 436
Rotational speed	1 800 rpm	Profile of guide vanes	Howell C4
Wheel diameter	600 mm		
Hub diameter	350 mm		
Number of moving blades	12		
Number of guide vanes	15		

fluctuation, measured in method 2, abscissa is taken from 5 to 2000 c/sec. But when the result was measured by method 1 the abscissa is taken from 5 to 5000 c/sec.

To find the magnitude of the measured total pressure fluctuation, we used the equipment as shown in Fig. 8. The experimental procedure is as follows: Insert the pick-up ① into the pressure pulse generator ②. The pressure pulse generator consists of the magnet ③, the voice coil ④, the vibration disk ⑤, the can ⑥ and the pressure gauge ⑦. The output of this pressure gauge is amplified by the strain meter ⑧, and its amplitude is recorded by the electromagnetic oscillograph ⑨. At first, turn the three-way cock as shown by ① in Fig. 8, and then record the initial displacement of the electromagnetic oscillograph h_0 mm. Then turn the three-way cock as shown by ② in Fig. 8, and add the pressure in the can by pouring alcohol into the mouth of the U-tube manometer ⑤. And record the displacement of the electromagnetic oscillograph h mm and the difference of the U-tube manometer h_{A1} mm. Turn back the cock as shown by ① again, then close the tube which is connecting the pressure pulse generator and the U-tube manometer at the nearest end from the pressure pulse generator ⑥. And vibrate the voice coil which is stuck to the vibration disk, and generate the pressure pulse of this frequency in the can. The electric current which is supplied by the oscillator ⑩ and amplifier ⑪ has frequency of 150 c/sec.

Fig. 8 Equipment to measure the magnitude of the total pressure fluctuation

Fig. 9 Frequency characteristic of frequency analyzer

Then read the amplitude h' mm of the electromagnetic oscillograph, and at the same time, the scale of the frequency analyzer ⑨. The output of the measuring instrument of pressure fluctuation ⑧ is amplified by the frequency analyzer ⑨. Then the following formula is obtained.

$$z \text{ db} = \gamma_{A1} h_{A1} h' / (h - h_0) \text{ kg/m}^2,$$

where z db is the reading of the frequency analyzer, and $\gamma_{A1} h_{A1}$ is the difference of the U-tube manometer in mmAq.

So, if we measure the total pressure fluctuation and obtain z' db as the magnitude of the fluctuation component of any frequency, then the magnitude of this component Δp kg/m² is

$$z - z' = 20 \log_{10} \left\{ \frac{\gamma_{A1} h_{A1} h'}{\Delta p (h - h_0)} \right\},$$

and we can rewrite in the form

$$\Delta p = \frac{\gamma_{A1} h_{A1} h' \times 10^{(z - z')/20}}{h - h_0} \text{ kg/m}^2.$$

The frequency analyzer used in this experiment is a constant-percentage bandwidth analyzer, i.e. the type NA-12 made by Japan Electronic Instrument Co., and Fig. 9 shows its characteristic curve.

3. Results and discussion

3.1 Results The total pressure fluctuations were measured at the places as shown in Fig. 10. The places which are shown in Fig. 10 (a) are chosen to measure the total pressure fluctuations in front of and at the back of the fan wheel.

(a) Measuring places (• shows the measuring places)

(b) Measuring places (measuring places lie on the chain line ⑦)

Fig. 10

Fig. 11 Magnitude to be subtracted from band level to obtain spectrum level

Fig. 12 Spectrum of total pressure fluctuation

Fig. 13 Spectrum of total pressure fluctuation

They are located at the mean radius of the annular section. The places shown in Fig. 10 (b) are chosen to measure the total pressure fluctuations in the diffuser. Their positions are comparatively far from the fan wheel. The difference in spectrum of pressure fluctuation as radii of measuring places are varied is more remarkable than that in spectrum as quantities of flow are varied. So the results at these places are shown for various radii, and then the quantity of flow is fixed at its maximum (Figs. 23 through 27). In Figs. 12 through 27, ordinate indicates a dimensionless value $\Delta\psi = \Delta p / (\rho u^2 / 2)$, where Δp is the amplitude of the total pressure fluctuation for any frequency in kg/m², u is the tip speed of the fan wheel in m/sec.

Besides, as shown in Fig. 9 the frequency analyzer used in this experiment has a set of proportional bandwidth filters. So, in case the measured phenomena consist not of simple tone, but of continuously distributed noise, correction must be made to get the spectrum level. The value of correction is shown in Fig. 11.

Some examples of test results i.e. Figs. 12 through 27, are classified as follows;

1) The spectra of the total pressure fluctuation which is measured in front of the fan wheel (Figs.

Fig. 14 Spectrum of total pressure fluctuation

Fig. 15 Spectrum of total pressure fluctuation

Fig. 16 Spectrum of total pressure fluctuation

12 through 14).

2) The spectra of the total pressure fluctuation which is measured at the back of the fan wheel (Figs. 15 through 20).

Fig. 17 Spectrum of total pressure fluctuation

Fig. 18 Spectrum of total pressure fluctuation

Fig. 19 Spectrum of total pressure fluctuation

Fig. 20 Spectrum of total pressure fluctuation

3) The spectra of the total pressure fluctuation which are measured at the back of the guide vanes (Figs. 21 and 22).

4) The spectra of the total pressure fluctuation which are measured in the diffuser (Figs. 23 through 27).

Fig. 21 Spectrum of total pressure fluctuation

Fig. 22 Spectrum of total pressure fluctuation

Fig. 23 Spectrum of total pressure fluctuation

Fig. 24 Spectrum of total pressure fluctuation

3.2 Discussion 1) Classification of the components of the total pressure fluctuation.

From Figs.12 through 27, it is possible to find that the total pressure fluctuation spectra consist of the following two parts:

The first one is the components that have the frequency of $(NZ)/60$ c/sec* or its multiples**, the magnitudes of which are definite, where N is the speed of the fan per minute, and Z is the number of blades in the fan. The fluctuation component that has the frequency of $(NZ)/60$ c/sec is called hereafter the component of fundamental frequency.

The second one is the components of frequency ranges which are considerably wide, and of magnitudes which are quite indefinite. This component is called the component of continuously distributed noise. Besides, there are the components that have

Measuring place ①
 $r=228$ mm ($r/r_a=0.707$)
 $\varphi=0.394$, $N=1800$ rpm (duct 2)

Fig. 25 Spectrum of total pressure fluctuation

Measuring place ①
 $r=270$ mm ($r/r_a=0.837$)
 $\varphi=0.394$, $N=1800$ rpm (duct 2)

Fig. 26 Spectrum of total pressure fluctuation

Measuring place ①
 $r=307$ mm ($r/r_a=0.949$)
 $\varphi=0.394$, $N=1800$ rpm (duct 2)

Fig. 27 Spectrum of total pressure fluctuation

* 360 c/sec when speed of the fan is 1800 rpm.

** twice 720 c/sec, three times 1080 c/sec, four times 1440 c/sec, five times 1800 c/sec.

the frequency of $N/60$ c/sec***, or its multiples, where N is the speed of the fan per minute. It is hard to distinguish these components from the vibration of the fan itself.

2) The total pressure fluctuations for various measuring places.

A) The spectra of the total pressure fluctuation in front of and at the back of the fan wheel under unstalled operating conditions.

As will be seen from Figs.12 and 14 the fluctuation components which have the frequency of $(NZ)/60$ c/sec are prominent, but their multiples are not so large. In addition, there are not any other components of fluctuation in front of the fan wheel. On the other hand, as will be seen from Figs.15 through 17, the components which have the frequency of $(NZ)/60$ c/sec are of comparable magnitude with the components which have the frequency of their multiples at the back of the fan wheel. Besides, as will be seen from Figs.15 through 17, and 19, components of continuously distributed noise are large compared with those which are measured in front of the fan wheel, although their distributions are not always similar under various operating conditions. In view of above results, these components seem to be caused by the disturbance of flow around the bodies in the fan.

Figs.12, 14, 15 and 19 are the results measured in front of and at the back of the fan wheel for various distances from the fan wheel. As will be seen, the magnitude of the component of fluctuation becomes smaller suddenly in front of the fan wheel as the distance from the fan wheel increases. But this is not so at the back of the fan wheel.

B) The spectra of the total pressure fluctuation in front of and at the back of the fan wheel under stalled operating conditions.

Figs.13 and 18 respectively show the spectra for the adjacent areas in front of and at the back of the fan wheel under stalled operating conditions. It is clear in these figures that the fluctuation component of continuously distributed noise is large and its frequency range is chiefly low, i.e. below 200 c/sec. As shown in Fig.22, this fluctuation which occurs under these operating conditions has no effect on the area at the back of the guide vanes. So the fluctuation which occurs under stalled operating conditions is enclosed in the neighbourhood of the fan wheel. There is a region of positive slope clearly in the pressure discharge characteristic curve of this fan, as shown in Fig.2. That the fluctuation of flow which occurs in front

*** 30 c/sec when speed of the fan is 1800 rpm.

of and at the back of the fan wheel under stalled operating conditions and which has no influence on the area at the back of the guide vanes agrees with the result of research by Ikui, Kunikiyo and Goto⁽²⁾.

C) The spectra of the total pressure fluctuation at the back of the guide vanes and in the diffuser.

As shown in Figs. 21 and 22, there is not much difference in the spectrum of the total pressure fluctuation at the back of the guide vanes as operating conditions are varied. But generally the components of continuously distributed noise are comparatively large in this place.

Figs. 23 through 27 show the results measured in the diffuser. As shown in these figures there are fluctuation components of continuously distributed noise which lie in the very low frequency range. There is much difference in the spectrum of the total pressure fluctuation, at the measuring places of various radii under the fixed operating conditions. These seem to be the result of the wake which occurs in the down stream of the boss.

D) The spectra of the total pressure fluctuation at the fixed operating conditions and the measuring places for various rotating speeds.

Some examples of spectra of the total pressure fluctuation, at the fixed operating conditions and measuring places, for various rotating speeds are shown in Figs. 15 through 17. From these figures the following results have been obtained.

The fluctuation component of fundamental frequency: This component has the frequency of $(NZ)/60$ c/sec. So its frequency varies as speed of the fan varies. The results shown in Figs. 15 through 17 were measured at the back of the fan wheel at the points whose distance from the fan wheel is 22.5 mm. Fig. 28 shows the component of fluctuation that has the frequency of $(NZ)/60$ c/sec, i. e. the component of fundamental frequency. It is picked up from the spectra, for example Figs. 15 through 18. The magnitude of ordinate, $\Delta\psi = \Delta p / (\rho u^2/2)$ in Fig. 28 is constant for various speeds of

Fig. 28 Fluctuation component of fundamental frequency [measuring place Fig. 10 (a), (c)]

the fan, if measuring places and operating conditions are fixed. That is to say, the magnitude of fluctuation component of fundamental frequency varies proportionately with the square of speed of the fan. This can be concluded from the results of our experiments within 60 mm in front of and at the back of the fan wheel. And also it is the same, even if the duct is changed. This statement is not always true in case when the measuring places are far from the fan wheel as shown in Fig. 29. The value of ordinate in Fig. 28, as previously indicated, show the peak value of the fluctuation components of fundamental frequency which are picked up from the spectra. In this case, strictly speaking, the characteristic of the filter band of the frequency analyzer must be considered, and its influence must be corrected. But it is practically impossible to do so. So this correction has not been made. The error in $\Delta\psi$ does not come into question under the operating conditions where the fluctuation component of fundamental frequency is large compared with the other fluctuation component ($\varphi > 0.2$). But under other operating conditions where the component of continuously distributed noise is large, compared with the component of fundamental frequency, the error must be considered. In this case the real value of $\Delta\psi$ is considered to be smaller than has been indicated in Fig. 28.

4. Conclusions

The total pressure fluctuation in the axial-flow fan is measured for various measuring places under various operating conditions. These researches have brought the following conclusions:

(1) The spectrum of total pressure fluctuation consists of the following two parts:

i) The component, whose frequency is $(NZ)/60$ c/sec or its multiples, where N is speed of the fan per minute; Z is number of moving blades.

ii) The component, whose frequency range is considerably wide, and whose magnitude is quite

Fig. 29 Fluctuation component of fundamental frequency [measuring place Fig. 10 (b), (d), duct 2]

indefinite, i.e. the fluctuation component of continuously distributed noise.

(2) Under unstalled operating conditions the component of fundamental frequency is large compared with the other component in front of the fan wheel. But under other operating conditions, or for other measuring places the component of continuously distributed noise becomes large. It becomes hard to distinguish the component of fundamental frequency from the other. From the results which are measured in the diffuser, the magnitude of the components of continuously distributed noise changes as the measuring places vary. We can conclude from these observations

that the fluctuation component of fundamental frequency arises from the fan wheel, and that the component of continuously distributed noise arises from the disturbance of the flow around bodies in the fan.

(3) The magnitude of the fluctuation component of fundamental frequency is proportional to the square of speed of the fan.

References

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