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QUASI 3-D FLOW DESIGN AND CHARACTERISTICS OF DIAGONAL FLOW IMPELLER WITH CIRCULAR ARC PLATE

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ABSTRACT

Basing on the principle of virtual equivalent velocity , this paper adapt the method of extending axis flow impeller to the quasi 3-D flow design of diagonal flow impeller with the experimental cascade data of circular arc blade. The performances of diagonal flow fan with outlet guide volute designed by this method, are compared with that designed by airfoil section cascade data. The reasonableness and reliability of this design method is verified.

1. Preface

It is been pay close attention increasingly to design and application of diagonal flow fan with NACA65 airfoil section [1]. A series of the fan products has succeed in operating in industry. It shows a fair economical benefit to substitute an equal thickness circular arc plate for airfoil section blade, under cases of either operating fan at low pressure or simplifying manufacture and decreasing cost of production paying a little reduce of performance of fan. From this point, this paper research is shown as below.

2. Quasi 3-D Flow Design of Diagonal Flow Impeller with Circular Arc Blade

(1). meridian surface calculation

The streamline distribution of meridian surface S_2 is found by use Novak Streamline Curvature Method (SCM) on equilibrium equation [2]of flow ration **q** along quasi-orthogonal line.

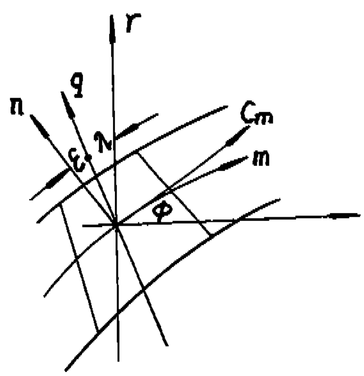

Fig.1 streamline of meridian surface

$$C_m^2 = e^{-\int A(q)dq}\left[\int B(q)e^{\int A(q)dq} + C\right] \quad (1)$$

integration constant C is determined by continues condition:

$$G = 2\pi \int_{q_h}^{q_c} \rho \gamma C_m \cos \varepsilon dq \tag{2}$$

where

$$A(q) = 2[-\frac{\sin\varepsilon}{C_m}\frac{\partial C_m}{\partial m} + \frac{\cos\varepsilon}{r_m} + \frac{1}{2}(\frac{1}{Q^*}\frac{dQ^*}{dq})] \tag{3}$$

$$B(q) = 2[\frac{1}{Q^*}\frac{d(HQ^*)}{dq} - \frac{C_\theta}{r}\frac{d(r\,C_\theta)}{dq} - \frac{C_\theta^2}{2}(\frac{1}{Q^*}\frac{dQ^*}{dq})] \tag{4}$$

according to the relation between entropy function Q* and total pressure loss coefficient ζ_p. The convergence condition of loss distribution is

$$Q^* = [1 - \frac{\zeta_p \rho w_1^2}{2P_{01}}(\frac{T_0}{T_1})^{-\frac{k}{k-1}}]^{\frac{k}{k-1}} \tag{5}$$

where

$$\zeta_p = \frac{0.008}{1 - 1.17\ln(D_{eq})}\frac{\sigma}{\cos\beta_2}(\frac{\cos\beta_1}{\cos\beta_2}\frac{r_1 b_1}{r_2 b_2})^2 \tag{6}$$

equivalent diffusion coefficient D is expressed as

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1}[1.12 + 0.61\frac{\cos^2\beta_1}{\sigma}(\tan\beta_1 - \tan\beta_2) \tag{7}$$

(2). Cascade Foil Selection on Revolution Surface

(I) First, relative velocity (W_m,W_θ) on average revolution surface (m-rθ) obtained from streamline of meridian surface is extended on arbitrary radial r* of cylinder extension surface (X-Y). The outlet velocities of cascade on X-Y surface are shown separately

$$W_{X1} = (r_1/r_*)W_{m1} \qquad W_{Y1} = (-r_1/r_*)W_{\theta 1}$$
$$W_{X2} = (r_2/r_*)W_{m2} \qquad W_{Y2} = (-r_2/r_*)W_{\theta 2} \tag{8}$$

(II) by follows definition, obtain flow coefficient φ and pressure coefficient ψ

$$\varphi = \frac{r_1 W_{m1} + r_2 W_{m2}}{2r^* u^*}, \qquad \psi = \varphi\frac{W_{r1} - W_{r2}}{W_{X\infty}} + X \tag{9}$$

where:

$$W_{X\infty} = (W_{X1} + W_{X2})/2\ , \quad X = ((r_2^2 - r_1^2)/r^{*2})/\varphi$$

(III) For use cascade data, according to virtual velocity triangle [4] shown in Fig.2, outlet relative airflow angle $\hat{\beta}_1$, $\hat{\beta}_2$ are determined:

$$\tan\hat{\beta}_1 = \tan\beta_1 + \frac{a}{2}X \tag{10}$$

$$\tan\hat{\beta}_2 = \tan\beta_2 - \frac{a}{2}X \tag{11}$$

$$\tan\beta_1 = W_{r1}/W_{X\infty} \tag{12}$$

$$\tan \beta_2 = W_{r2}/W_{X\infty} \tag{13}$$

where, constant a=0~1

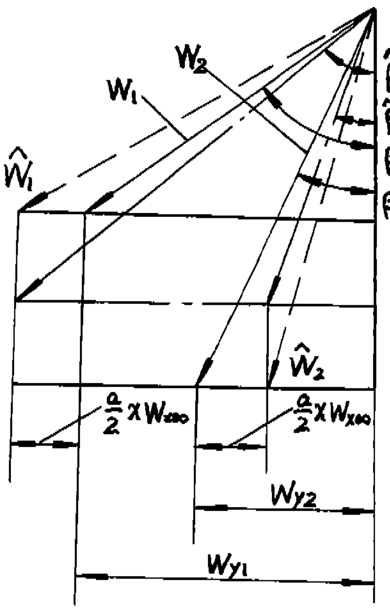

Fig.2 Virtual equivalent velocity triangle

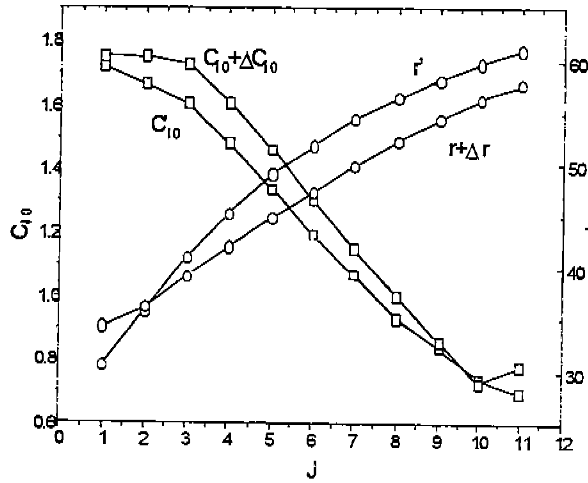

Fig.3 Curvature and stagger distribution of airfoil blade and circular blade

(IV) suppose solidity ratio σ, then basing on $\hat{\beta}_1, \Delta\beta(=\hat{\beta}_1 - \hat{\beta}_2)$ and σ, from cascade experimental data, check out center angle θ and stagger angle α . Therefor stagger angle $r = \hat{\beta}_1 - \alpha$ of circle arc cascade is obtained.

(V) substitute r to equation (14), compare suppose σ and calculated σ, iterate until suppose σ value is equal calculated σ value, and satisfied Deq≤1.9.

$$\sigma = \frac{X_2 - X_1}{\cos r} \frac{N}{2\pi r^*} \tag{14}$$

where N--blade number.

(VI) The relation between center angle of this circular arc blade and curvature of NACA 65 foil C_{l0} is

$$C_{\ell 0} = 9.066 \tan(\theta/4)$$

(VII) Final, the cascade geometry of diagonal flow impeller is found out by converting the cascade geometry in prassil transformation surface to the physic surface.

$$dx = \left(\frac{r^*}{r}\right)dm, dy = -r^* d\theta \tag{15}$$

3. Design Samples and Calculation Results

A prototype fan using circular arc blade with outlet guide vane has been made. The design parameters are shown in Table 1.

Table 1 design parameter

flow (m^3/min)	96	impeller blade number	6
total pressure (Pa)	1548	length thick ratio	tip 2%, root 2.5%
rotate velocity (rpm)	2900	guide blade number	13
diameter (mm)	400	length thick ratio	2%
flow type	free vortex	specific velocity	14.86

The comparison results between this diagonal flow impeller with that in [4]. Generally, the curvature of airfoil from Schlichting's singularity method is little bigger than that from this method and change trend is identical.

The main cascade geometric parameter on 6 section along root to tip of blade are shown in

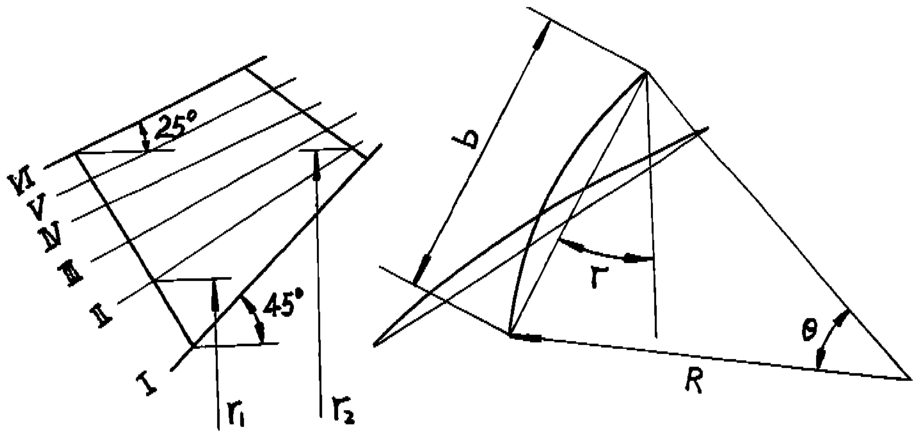

Fig.4 Diagonal flow impeller

Table 2.

Section	r_1 (mm)	r_2(mm)	θ°	b (mm)	R (mm)	r°
I	59.15	150	43	160	213.2	30.6
II	92.24	157.7	40	165	241.3	40.8
III	114.5	167	34	173	297.4	48.3
IV	131.9	177.3	28	181	374.4	53.7
V	146.8	188.3	23	187	472.8	57.9
VI	160	200	17.6	194	637	6.1

4. The characteristics of diagonal flow fan in different tip clearance

According to P.R.China National Standard GB1236-85 and GB288-82, Performance experiment is carry out under tip clearance s=0.5,1.0,1.5,2.0. The main experimental results are shown in Fig.5, Fig.6. Comparison of performance in different tip clearance is shown in Table 3.

Table 3. The design characteristics in different tip clearance

	Q (m^3/min)	P (Pa)	P_{st} (Pa)	η_{st}(%)	η (%)	L_{SA} (dB)	L_A (dB)
0.5	104.1	1597.9	1470.2	78.3	85.12	20.6	85
1.0	106	1558.6	1425.9	76	83.17	21.05	85.33
1.5	105.8	1513.8	1381.2	73.6	80.17	22.61	86.63
2.0	105.5	1501.4	1369.9	72.78	79.76	24.22	88.16

The performance is best in tip clearance s=0.5mm, in this situation total pressure efficiency η=85%, A noise level L_{SA}=20.6dB.

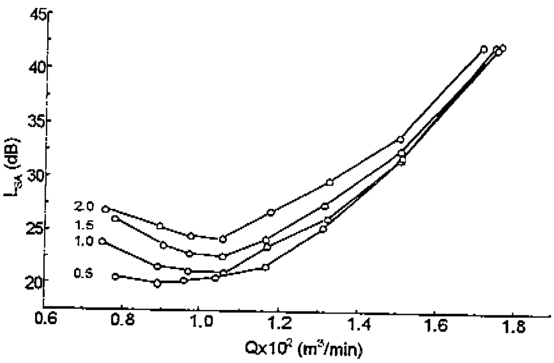

Fig.5 The Noise in different tip clearance

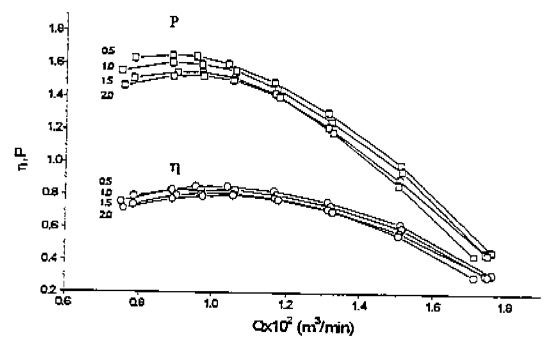

Fig.6 The Characteristics in different tip clearance

5. Conclusion

(1) The design method of diagonal flow impeller with circular arc blade use virtual equivalent velocity is reasonable

(2) The reliability and application of this design method are verified through performance experiment results in different tip clearance.

(3) The performance of this diagonal flow fan is best in tip clearance s=0.5mm

Reference

[1] Wu Keqi, Cai Zhaolin,Ou Yingda: A Design Method of Diagonal Flow Fan by Quasi-Three Dimension, Journal of Engineering Thermophysics, Vol.7, No.2, 1986, PP.124- 126

[2] M.Inoue,Wu Keqi, et al , A Design of Diagonal Impeller by means of SCM and Cascade Data, Proc. Of China-Japan Joint Conference on Hydraulic Machinery and equipment, Oct. 1984, pp21-30

[3] Lieblein,S., Loss and Stall Analysis of compressor Cascade, Trans. ASME, ser. D, Vol.18, No.3, 1959,pp387

[4] M.Inoue,Wu Keqi, Determination of a blade Element of a Diagonal Impeller by use of Cascade Data.