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THE EXPERIMENT AND ANALYSIS OF DRAG COEFFICIENT OF THE RING-TYPE VALVE

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ABSTRACT

In this Paper, the distribution of pressure acting on the surface of valve plate, and the drag coefficient against h/b were measured. based on the experiment, a flat flow theory for the valve channel and, a nozzle flow theory for the clearance between plate and seat of the valve, were used to develop the relative mathematical models.

They were compared with several former results and some conclusions were made.

INTRODUCTION

The drag coefficient is an important parameter for studying the dynamics of compressor valve. It has been mentioned by several papers: /1/, /2/, /3/, /4/.

The purpose of this paper is using experiment and analysis to develop a mathematical model of drag coefficient of the ring type valve.

The definition of drag coefficient in this paper is as follows:

$$\beta = F / (\Delta p\ A) \qquad (1)$$

So, the problem is how to find the rules of the Δp and F.

The test result of a valve in a smoke tunnel showed in fig.1 /5/. It was shown that the flux line in a valve channel has three characters: the first is a stagnation point in the middle of the width of valve plate; the second is two separations at the corners of valve plate and seat; the third is in a macroscopic view, the flux lines in a valve channel is symmetric. These characters are the base of the following discussion.

EXPERIMENTAL MODELS

For the purpose of determining the distribution of pressure acting on surface of the valve plate, a magnified rectangular plate was used as valve plate which put in a stable blow system shown in fig.2. The pressure distribution being measured are plotted in fig.3.

Then a special device shown in fig.4 was used to measure the acting force acting on the plate of a real valve, and the experimental results of drag coefficient are plotted in fig.5.

FLAT FLOW MODEL

According to the condition of fig.1, the flow in a valve channel was treated as two dimensions as in fig.6 and was assumed that:

1) The flow field is ateady, incompressible, non-rotary and, it satisfies flat flow potential condition;

2) The channel of valve was simplifyed as in fig.6, the valve stopper was ignored.

According to the fluid dynamics of flat flow, the flow field must have a certain complex potential as follows

$$\chi = \phi(x, y) + i\,\psi(x, y) \tag{2}$$

where $\phi(x, y)$ is a potential function and $\psi(x, y)$ is a flux function.

The relationship between the velocity in flow field and the eq.(2) is

$$\begin{aligned} U(x, y) &= \frac{\partial \phi}{\partial x} = \frac{\partial \psi}{\partial y} \\ V(x, y) &= \frac{\partial \phi}{\partial y} = -\frac{\partial \psi}{\partial x} \end{aligned} \tag{3}$$

in eq.(3) ϕ, ψ should satisfy Caeechy-Riemann equation

$$\begin{aligned} \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} &= 0 \\ \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} &= 0 \end{aligned} \tag{4}$$

Then

$$\frac{\partial \chi}{\partial z} = U - i\,V \tag{5}$$

where the real portion of eq.(5) in right hand is a component of velocity on x axis, and the imagnary portion is a minus component of velocity on y axis.

Developping eq.(5), we got the distribution of pressure acting on the surface of valve plate and it was plotted in fig.7.

Based on above results, the following drag coefficient expression can be got:

$$\beta = 1 - \frac{2}{\pi}\frac{b}{e}\left(\frac{1}{\sqrt{a_1}} - \sqrt{\frac{1}{a_1} - 1}\right)\left[\sqrt{\frac{a_2 - 1}{a_2}}\ln\left(\sqrt{a_2} + \sqrt{a_2 - 1}\right) + \sqrt{\frac{1 - a_1}{a_1}}\left(\frac{\pi}{2} - \operatorname{arctg}\sqrt{\frac{a_1}{1 - a_1}}\right) - \frac{\pi}{2}\left(\frac{1}{\sqrt{a_1}} - \frac{1}{\sqrt{a_2}}\right)\right] \tag{6}$$

where a_1 and a_2 — function of the stractural parameter of b, e, h, etc.

The mathematical model of pressure distribution does not agree with the result of experiment in the part of clearance. The tendency of drag coefficient against h/b is also too even (fig.8). Therefore, a correction calculation was used in next paragraph.

NOZZLE FLOW MODEL

The valve clearance was considered as a nozzle, and considered that:

1) the nozzle shape of cross section is a function of the lift of valve plate(fig.9);

2) the changable rate of divergent portion is smaller than that of convergent portion, hence, the shape of convergent is expressed by quadratic function and, divergent is expressed by linear function.

Consequently, the flow area that accordance with a unit length of the valve plate circle is as follows:

$$A = \begin{cases} h + 2(A_{min} - h)\dfrac{x - b/2}{x_{min} - b/2} - (A_{min} - h)\left(\dfrac{x - b/2}{x_{min} - b/2}\right)^2 & x \leq x_{min} \\ A_{min} + C(\,x - x_{min}\,) & x \geq x_{min} \end{cases} \qquad (7)$$

where $A_{min} = h_{min}(\,1.112 + 0.006b/h\,)$ (8)

The position of minimum area is

$$x_{min} = 0.37\,b\left(1 - \frac{1}{1+7.6h/b}\right) + b/2 \qquad (9)$$

C is the changable rate of the area of divergent portion and

$$C = 0.2\,\frac{h - A_{min}}{x_{min} - b/2}$$

The results of the correction is plotted in fig.10. There are a deviation of β between calculation and experiment, it is caused by pressure drop in valve stopper.

THE EMPIRICAL EQUATION

The corrected analysis mathematical model is rather complex. based on the identity of experimental data and, considered the main factor of the influence, the drag coefficient can be expressed by an approxiative equation as follows:

$$\beta = \frac{A_b}{A_e} \quad 1.297 + 2.098\,\frac{h}{b} - 2.433\left(\frac{h}{b}\right)^2 \qquad (10)$$

COMPARISION

Various former results in fig.11, fig.12, fig.13 and fig.14 showed evidently that after h/b=0.1, the tendency of β - h/b in fig.11, fig.12 and this paper is analogous, even the definitions of horizontal coordinate have some differences. But the more close h/b = 0 the more analogous in fig.14.

CONCLUSION

1) The analysis and experiment of β - h/b in this paper are are basically analogous.

2) The tendency of β - h/b (after h/b=0.1) in this paper is the same with references/1/,/2/.

3) To simplify calculation, the empirical equation(10) above might be recommended to use in study of valve dynamics.

NOMENCLATURE

A_b - effective flow section area of valve seat channel

A_e - area of the valve plate opposing the gas flow

b - width of channel section of valve seat

e - radius width of valve plate

F - force of flow action which acts on the valve plate

H - maximum lift of valve plate

h - lift of valve plate

h_{min} - minmum altitude of the jet nozzle flow in valve clearance

Z - complex

β - drag coefficient of compressor valve

Φ - potential of velocity

Ψ - flux function

χ - complex potential

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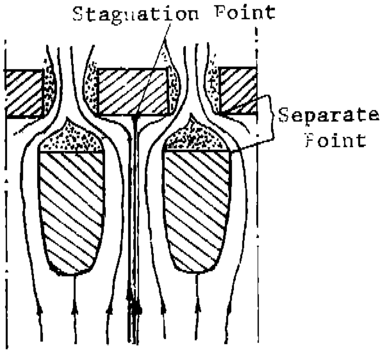


Fig. 1

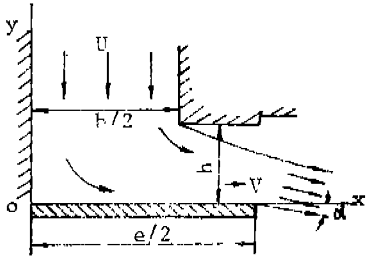


Fig. 6

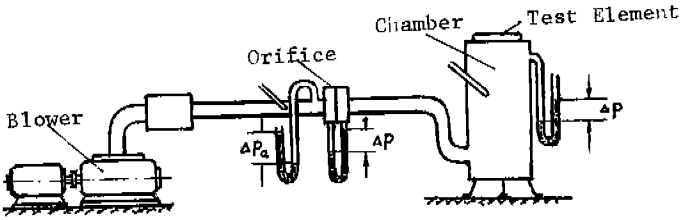
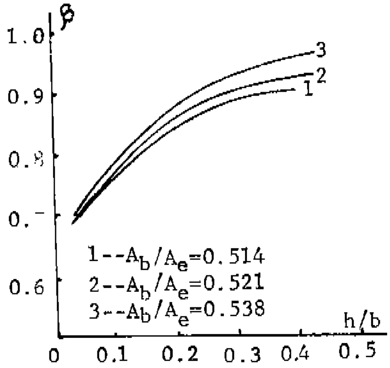


Fig.2



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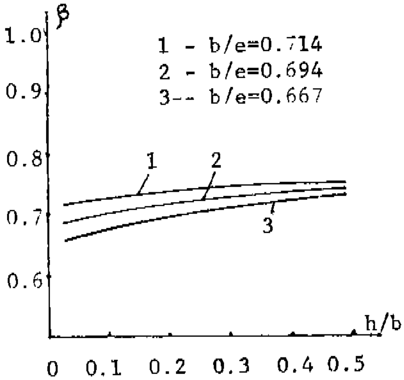

Fig. 8

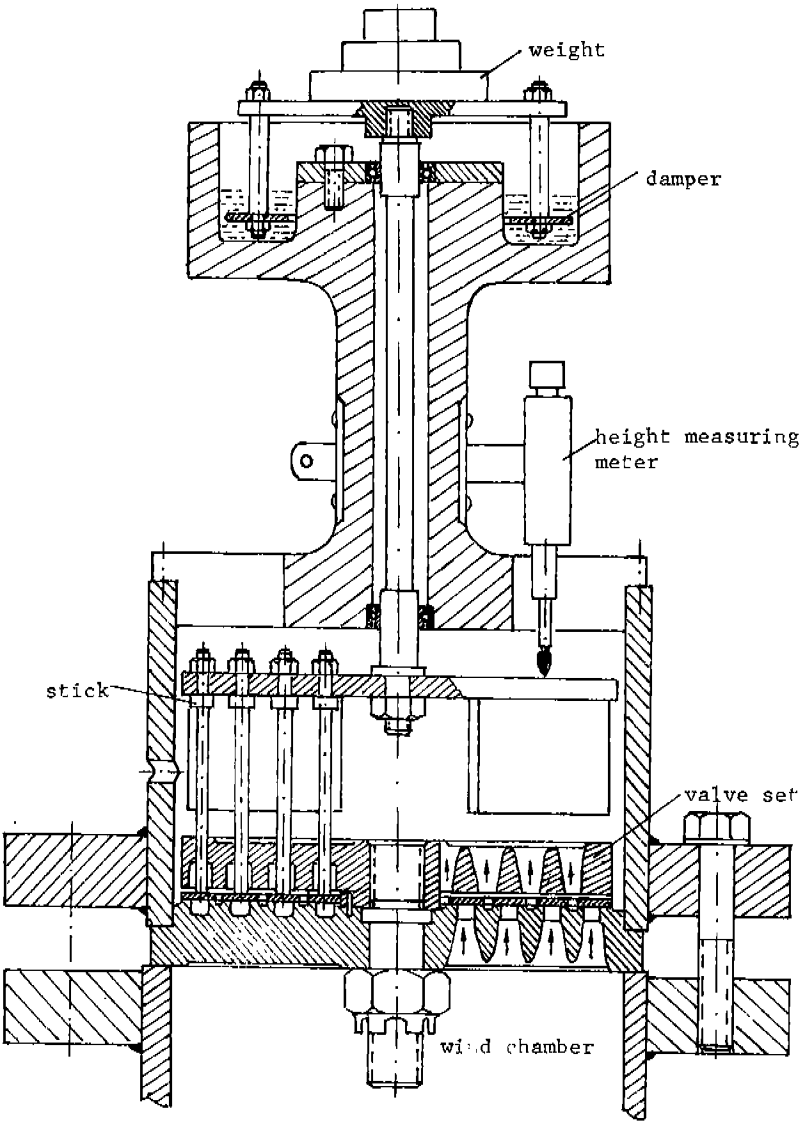
weight
damper
height measuring meter
stick
valve set
wind chamber

Fig. 4

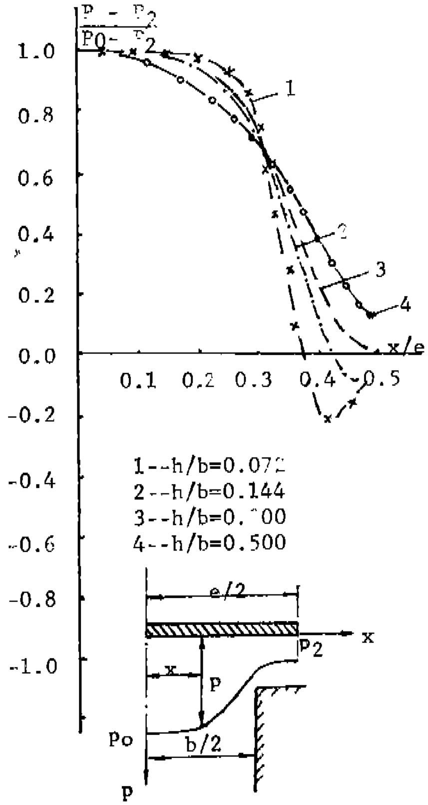

Fig. 3

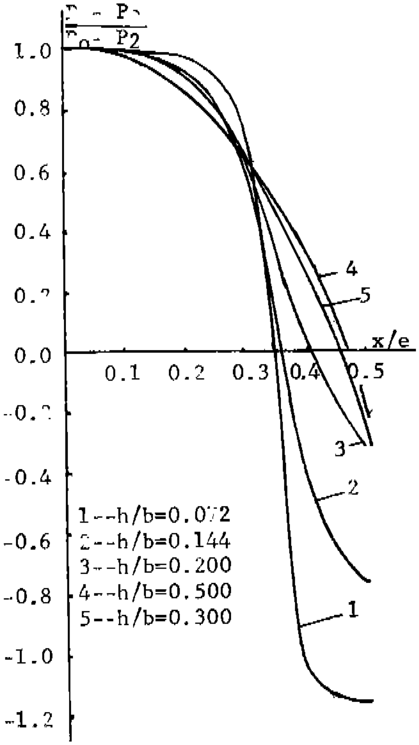

Fig. 7

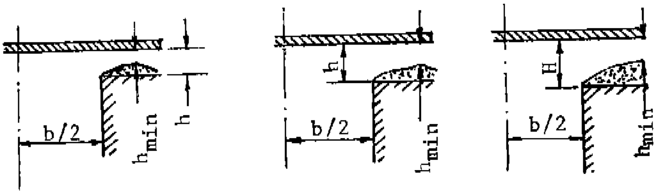

Fig. 9

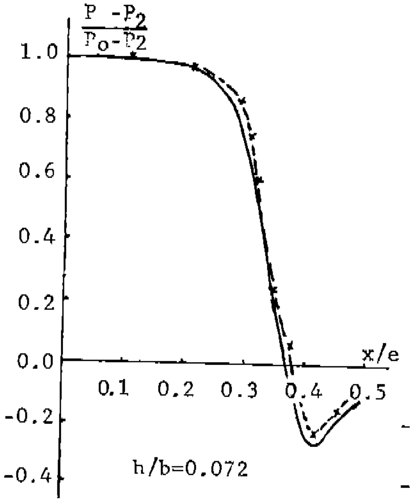

Fig. 10(a)

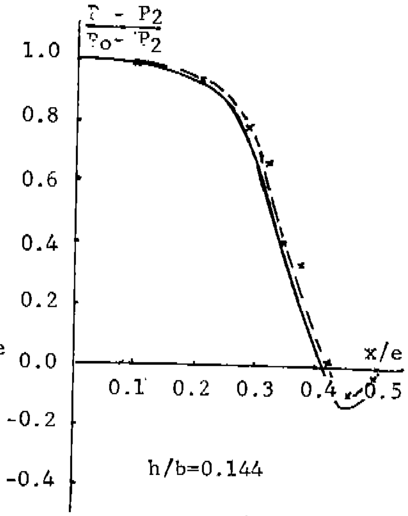

Fig. 10(b)

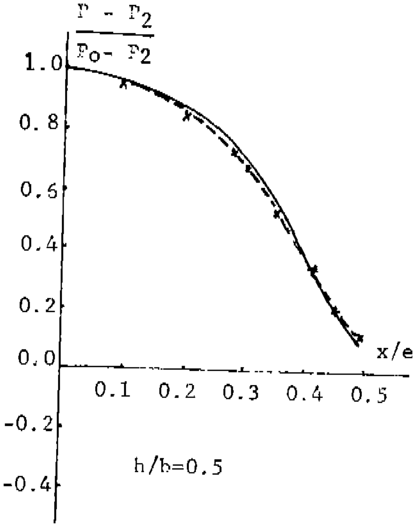

Fig. 10(c)

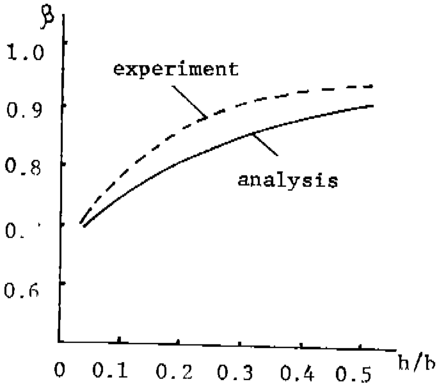

Fig. 10(d)

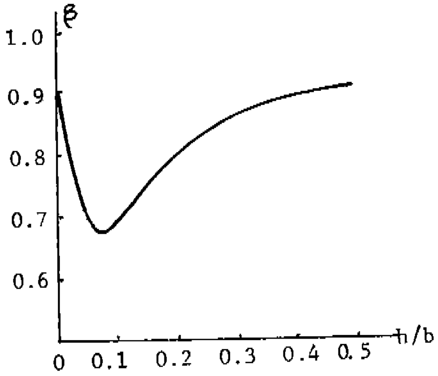

Fig. 11 Reference/1/

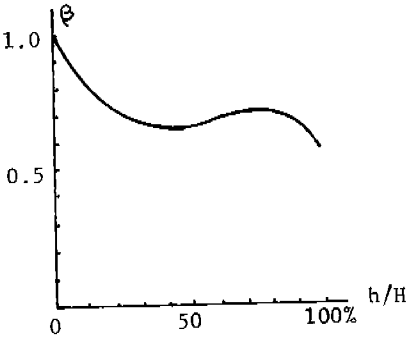

Fig. 13 Reference/4/

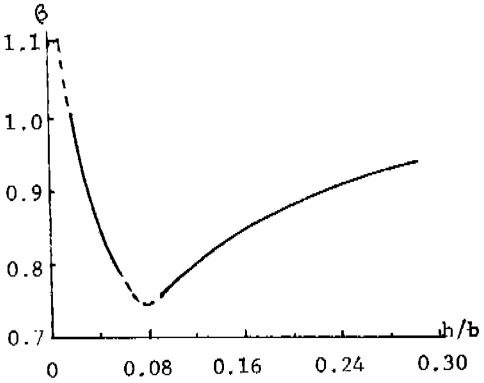

Fig. 12 Reference/2/

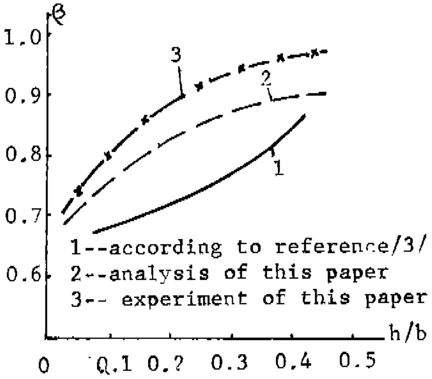

Fig. 14