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Characteristics of Disc Valves in Angle-Valve Type Chambers

(Experimental Research on Disc Valves, 5th Report)*

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In an angle-valve type valve box specially prepared a series of experiments were carried out on disc valves with flat-or conical-seat under a head of about two meters. Thus the relations between valve lift, discharge and lifting force were studied, whereby many factors in the characteristics of disc valves under these conditions were made clear.

1. Introduction

We have hitherto given four reports; three⁽¹⁾ of them on the experiments performed on disc valves with flat-or conical-seat, placed in a vertical cylinder type chamber (abbreviated V. C. T. C.); and the fourth⁽²⁾ on the experiments made on flat-seated valves of high-lift safety-valve type, discharging water into the air or into a vessel filled with water. In the present paper we treat the characteristics of disc valves placed in an angle-valve type chamber (abbreviated A. V. T. C.). The experiment was carried out in the Hydraulic Laboratory of Waseda University, Tokyo.

2. Experimental apparatus

The assembled measuring equipment mounted on a valve box is illustrated in Fig. 1. The end of a 6 inches cast-iron pipe leading to an overflow tank is gradually reduced to 4 inches in diameter and is connected to a short pipe of cast iron of the same diameter, on which is fitted the valve box concerned. The box is made of cast iron, with inside diameter and height 100 and 63 mm respectively, and is provided on the side with an exit hole of 50 mm diameter.

Two series of experiments were performed with this arrangement. In the first series of experiments, a 51 mm brass pipe of about three meters long provided with a pipe orifice was fitted in this exit hole as an exhaust pipe [see Fig. 1(a)]. In the second series the diameter of the exit hole was reduced to 30.4 mm and a brass pipe of the same diameter and about 150 cm long was used as an exhaust pipe [see Fig. 5(a)]. We called

(a) General arrangement

(b) Measuring equipment

Fig. 1 Experimental arrangement of angle-valve type chamber ($d_e=50$)

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the first series Experiments on A. V. T. C. ($d_e=50$) and the second series Experiments on A. V. T. C. ($d_e=30.4$), denoting exit-hole diameter by d_e .

In each of them discharge and lifting force were measured for a wide range of lift of disc valves with flat- or conical-seat. The valve seats for these valves were made of brass and fitted on the top end of the valve port with inside diameter of 30 mm. Cylindrical bushes of five kinds were put into the valve box, three of them being made of brass with diameters of 36, 39 and 42 mm and the other two of cast iron with diameters of 48 and 60 mm.

When d_0 denotes valve-port diameter, d valve diameter and D inside diameter of chamber, we get, by combining them in several ways, many cases of diametral ratios d/d_0 and D/d_0 .

3. Methods of measurements and computations

Statical head h_I , referred to the valve-seat face, was measured, by means of a manometer, at a hole I on the wall of a 4 inches pipe which forms the entrance to the valve box. When $v_I^2/2g$ represents the velocity head in the 4 inches pipe the total head at the point I is,

$$H_I = h_I + v_I^2/2g$$

which is taken as the total head on the entrance side.

As to the exit side we take the total head at the flange face II of the valve box. Piezometer holes were made at three points III, IV and V on the exhaust pipe [see Figs. 1 (a) and 5 (a)].

We computed the frictional head-loss between points II and IV, denoted h_l (II~IV), from that between points III and V, assuming, though not exactly, that they are in proportion to pipe length. When h_N stands for the statical head, referred to the valve-seat face, and $h_N^2/2g$ for the velocity head in the exhaust pipe at the hole IV, the total head H_{II} at the flange face II is,

$$H_{II} = h_N + v_N^2/2g + h_l(\text{II-N})$$

Then we define the effective head H between the piezometer hole I and the flange face II as follows,

$$H = H_I - H_{II} = (h_I + v_I^2/2g) - (h_N + h_l(\text{II-N}) + v_N^2/2g) \dots (1)$$

H varied from 1.8 m to 1.6 m in experiments for the case of $d_e=50$ mm and from 1.8 m to 0.7 m in those for the case of $d_e=30.4$ mm. In the case of $d_e=50$ the pressure head at the piezometer hole IV was adjusted by means of a regulating valve fitted at the end of exhaust pipe. In the

case of $d_e=30.4$ water was discharged freely out of the exhaust pipe.

The valves to be tested were set at any desired lift by means of a screw bolt and a dial gauge.

Discharge Q was determined in the following way. In the case of 51 mm exhaust pipe a pipe orifice (calibrated from time to time) was used for larger flow of water. In all the other cases we used a stop watch and two measuring vessels of different capacity.

To determine the lifting force of a valve due to the water flowing up, weights were added little by little on a flat-pan fitted to the valve spindle until the downward force just overcomes the lifting force and makes the valve suddenly fall off. In this condition the total dead weight loaded on the valve (discounting the buoyancy for the submerged part) is equal to the lifting force P .

We write Q for discharge, $d_0=2r_0$ for the inside diameter of valve port, hence $a_0=\pi r_0^2$ for port area, H for effective head and g for the acceleration of gravity.

Then non-dimensional discharge q is defined as

$$q = Q/a_0\sqrt{2gH} \dots (2)$$

If discharge coefficient for a disc valve lifted by l is expressed as

$$c = Q/\pi d_0 l \sqrt{2gH} \dots (3)$$

the relation between q and c is

$$q/c = 4l/d_0 \dots (4)$$

When P denotes lifting force, γ weight of water, and hence γH the effective pressure intensity, non-dimensional lifting force is written as

$$p = P/a_0\gamma H \dots (5)$$

From Eqs. (2) and (5) we have

$$\frac{q^2}{p} = \frac{\gamma}{2ga_0} \frac{Q^2}{P} \dots (6)$$

4. Experiments on A. V. T. C. ($d_e=50$)

With the valve box ($d_e=50$) a series of experiments were carried out on five valves made of brass. Three of them are flat-seated and 30, 33 and 36 mm in diameter, and the other two conical-

Fig. 2 Valve in A. V. T. C. ($d_e=50$)

Table 1 Diametral relations between port d_0 , valve d , and chamber D in A. V. T. C. ($d_e=30.4$).
Figures within the enclosure are for the case of $d_e=50$.

Type of valve	d	$\frac{d}{d_0}$	d_1	D mm	36	39	42	48	60	100
	mm		mm	D/d_0	1.20	1.30	1.40	1.60	2.00	3.33
Flat-seated	30	1.00	34.2	$\frac{D}{d}$	1.20	1.30	1.40	1.60	2.00	3.33
	33	1.10	34.2		1.09	1.18	1.27	1.45	1.82	3.03
	36	1.20	34.2		1.00	1.08	1.17	1.33	1.67	2.78
	39	1.30	34.2		—	1.00	1.08	1.23	1.54	2.56
	42	1.40	34.2		—	—	1.00	1.14	1.43	2.38
Conical-seated	33	1.10	33		1.09	1.18	1.27	1.45	1.82	3.03
	36	1.20	36		1.00	1.08	1.17	1.33	1.67	2.78

$d_0=30$ mm ; d_1 is for external diameter of valve-seat face.

(a) $d=30$ mm, $d/d_0=1.0$ (b) $d=33$ mm, $d/d_0=1.1$ (c) $d=36$ mm, $d/d_0=1.2$
Fig. 3 Characteristics of flat-seated valves in A. V. T. C. ($d_e=50$)

-seated and 33 and 36 mm in diameter. We used two cast-iron cylindrical bushes of 48 and 60 mm in inside diameter and each having a side hole of 50mm diameter [see Figs. 1 (b) and 2]. Thus, the inside diameter of the box being 100 mm, three kinds of chamber diameters were available in these experiments. The diametral relations between valve port d_0 , valve d and valve chamber D tested in various combinations are given in Table 1 by the figures within the enclosure.

The values of q , c and p computed from the results of these experiments are plotted against l/d_0 and illustrated in Figs. 3 and 4.

(a) $d=33$ mm, $d/d_0=1.1$ (b) $d=36$ mm, $d/d_0=1.2$
Fig. 4 Characteristics of conical-seated valves in A.V.T.C. ($d_e=50$)

5. Experiments on A. V. T. C.

($d_e=30.4$)

In these experiments the diameter of exit hole of the valve box was reduced to 30.4 mm by casting solder metal into the 50 mm side hole. The center line of hole was brought to a height of 16.7 mm above the valve-seat face and the top-side was lowered to 45 mm [see Fig. 5 (b)]. We prepared two kinds of flat-seated valves made of brass whose diameters were 39 and 42 mm. The diameter of the exit holes of two cylindrical bushes used in the former experiments was reduced to 30.4 mm by casting solder metal into the side hole. Three brass bushes with the inside diameter of 36, 39 and 42 mm and each having a side hole of 30.4 mm diameter were newly added. Hence we were able to test the seven valves combined with the chambers of six kinds of inside diameter, the diametral relations of which are given in Table 1. The values of q , c and p computed from the results of experiments are plotted against l/d_0 and illustrated in Figs. 6 and 7.

The characteristics of a disc valve placed in a chamber of the same diameter, that is, $d=D$, is quite peculiar as shown in Fig. 8. In a V.C. T.C. discharge remains zero at any valve lift when $d=D$. In an A.V.T.C. with D equal to d , however, water escapes through the side hole and discharge increases gradually as the valve opens.

Moreover it is quite remarkable that lifting force in this type of chamber attains so high a value as was not previously expected.

Fig. 7 Characteristics of conical-seated valves in A. V. T. C. ($d_e=30.4$)

6. Pressure distribution on the valve faces

To ascertain the cause of the extraordinary large lifting force on the valve, we measured the pressure distributions on the valve faces. For this purpose we made seven holes of 1 mm diameter in each of two valves of 36 mm diameter, one with flat-seat and the other with conical-seat, as shown in Fig. 9. From each of the holes a thin vinyl tube was led through the valve stem to respective manometer, by which pressure head referred to the valve-seat face was read. By rotating the valve about its stem by an angle of 45 degrees in order, pressure heads for each hole were measured at eight angle-positions. In this way each of the two valves was tested, combined with three cylindrical bushes of diameters of 36, 39 and 42 mm.

As an example the mode of pressure distribution on the flat-seated valve in the case of $d=D=36$ mm is shown in Table 2. When the valve-lift is $l=9$ mm, that is, when the valve finds itself nearly on the center line of the exit hole, the pressure heads on the back side of the valve fall down very markedly, while at a lift $l=18$ mm the pressures recover to a certain degree. These phenomena are possibly caused by the jet from the valve port, as illustrated in Fig. 10, inducing the water at the back of the valve and lowering the pressure there.

Fig. 8 Characteristics of valves in A. V. T. C. ($d_e=30.4$) when $d=D$

Fig. 9 Measuring equipment for pressure distribution on valve faces in A. V. T. C. ($d=30.4$)

Table 2 Pressure distribution on the faces of flat-seated valve in A. V. T. C. ($d_e=30.4$) where $d=D=36$ mm. (a) $l=9$ mm ($l/d_0=0.30$)

	Number of piezometer holes						
	1	2	3	4	5	6	7
Angle position							
a	177.2	37.2	-40.6	-40.3	-41.0	-40.6	-41.1
b	177.2	125.3	-40.8	-41.1	-42.9	-41.1	-41.1
c	177.2	175.7	A				-41.1
d	177.2	176.6					-40.8
e	177.5	177.1					-43.3
f	177.1	176.2					-43.1
g	177.1	174.8					-42.9
h	177.1	90.2	-39.8	-42.3	-39.9	-43.3	-39.7
Mean value	177.2					-42.0	-40.7

(b) $l=18$ mm ($l/d_0=0.60$)

	Number of piezometer holes						
	1	2	3	4	5	6	7
Angle position							
a	174.7	66.5	1.7	-4.7	-8.5	-6.6	-5.4
b	174.5	85.5	-5.9	-6.1	-7.4	-6.8	-6.0
c	174.8	163.9	B				-8.0
d	175.2	161.5					-8.3
e	175.4	159.6					-6.0
f	174.9	161.7					-6.2
g	175.0	163.0					-7.1
h	174.8	78.9	-8.3	-5.3	-5.5	-7.3	-7.3
Mean value	174.9					-7.0	-6.8

A and B are cases where it is impossible to measure pressure, since the faces of valve and wall are in contact.

(a) Flat-seated valve (b) Conical-seated valve

Fig. 10 Action of issuing jet in A. V. T. C. ($d_e=30.4$) when $d=D$

The conical-seated valve with a diametral relation of $d=D=36$ mm gives the same mode of pressure distribution as in the case of flat-seated valve, although the lifting force on the valve was not so large, probably owing to the different shape of valve-disc edge.

7. Height Z of the center line of exit hole

Into the side hole of 50 mm diameter of the valve box with top-side height of 63 mm as used in the first experiment, an exit hole of 30.4 mm diameter was made by casting solder metal, so as to make its center height $Z=16.7$, 26.7 and 32.5 mm above the valve-seat face. The valves of diameter $d=36$ mm with flat- or conical-seat were tested each combined with a chamber of diameter

Table 3 Roundness r of exit-hole edge and $\Delta Q/Q'$ % in A. V. T. C. ($d_e=30.4$), $\Delta Q=Q-Q'$, Q' for the case $r=0$.
(Flat-seated valve $D/d=48/36$, $Z=26.7$, $d_e=30.4$ mm)

l/d_0	r mm		
	3	5	7
0.05	0.6	0.4	0.6
0.10	2.1	2.1	1.9
0.20	4.0	4.6	5.6
0.30	6.5	6.3	8.1
0.40	8.0	8.1	10.1
0.50	7.8	8.4	8.8

Table 4 Top-side height L and $\Delta Q/Q'$ and $\Delta P/P'$ in A. V. T. C. ($d_e=30.4$), $\Delta Q=Q'-Q$, $\Delta P=P'-P$, Q' , P' for the case $L=33$ mm.
(Flat-seated valve $D/d=48/36$, $Z=16.7$, $r=0$, $d_e=30.4$ mm)

L mm	45	63	45	63
l/d_0	$\Delta Q/Q'$ %		$\Delta P/P'$ %	
0.05	-1.0	0.4	0.9	0.4
0.10	0.1	1.3	2.3	3.2
0.15	2.3	3.0	2.4	3.8
0.20	4.4	7.5	-3.3	0.1
0.30	2.9	6.1	-7.0	-0.3
0.40	2.2	5.0	—	—
0.50	-2.4	0.1	—	—

(a) Flat-seated valve

(b) Conical-seated valve

Fig. 11 Effect of center height Z of exit-hole in A. V. T. C. ($d_e=30.4$) for valves $D/d=48/36$.

$D=48$ mm. The results thus obtained are illustrated in Fig. 11.

8. Roundness r of the edge of exit hole

In the valve box ($d_e=30.4$) the top-side height L was set at 63 mm and center height Z of the side hole at 26.7 mm. Then the roundness of the edge of exit hole was varied in four ways as $r=0, 3, 5$ and 7 mm in radius. In these conditions the flat-seated valve of diameter $d=36$ mm was tested, combined with the chamber of diameter $D=48$ mm, the results of which are shown in Table 3.

9. Top-side height L of chamber

In the valve box with $d_e=30.4$, $Z=16.7$ and

$r=0$ the top-side height was varied in three ways as $L=33, 45$ and 63 mm above the chamber bottom, where $L=33$ is a value a little larger than $Z+d_e/2$. The flat-seated valve of diameter $d=36$ was tested, combined with the chamber of diameter $D=48$ and gave the results as shown in Table 4.

References

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