IN-LINE FORCES ON OSCILLATING MULTIDISC IN A FLUID FLOW

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In a previous paper[2] we discussed the fluid resistance acting on an oscillating single-disc in a fluid flow and proposed a correlation between the energy dissipations calculated from the fluid resistance.

In this paper we deal with the fluid force acting on an oscillating multidisc and evaluate the effect of the distance between the discs on the fluid force.

1. Experimental

The experimental apparatus and the procedure were the same as used in our previous study.[2] The test body (multidisc) consisted of five discs, each of diameter 0.06 m. A supporting rod 8.0 mm in diameter was used to hold the five discs parallel to one another. The fluctuating in-line force was sampled with the aid of a computer through an A-D converter. The sampling rate was such that one oscillation cycle was resolved into 64 data points. The in-line force sampled was the arithmetic mean of 20 cycles of data.

The drag coefficient of the multidisc is denoted as C_{d5}, and is calculated by Fourier analysis[1] as follows:

$$C_{d5}=\int_0^{2\pi} F\sin\omega t d(\omega t)\Bigg/\left[\frac{1}{2}\int_0^{2\pi}\{\rho(\pi/4)d^2(a\omega\sin\omega t+U_0)\times|-a\omega\sin\omega t-U_0|\sin\omega t\}d(\omega t)\right] \quad (1)$$

where F is the measured in-line force acting on the multidisc, d is the diameter of discs, ρ is the fluid density, a is the amplitude of oscillation, ω is the angular frequency and U_0 is the flowing fluid velocity.

The experimental conditions are listed in **Table 1**. The ratio of the distance between discs to the disc diameter L/d ranged from 0.4 to 1.5.

2. Results and Discussion

Figure 1 shows the relationship between E_{fv}/E_f and E_f/E_v. E_{fv}, E_v and E_f are respectively the energy dissipations for the oscillating multidisc in a fluid flow, in a fluid at rest, and for the stationary multidisc in a fluid flow. These are time-averaged and are calculated by multiplying the instantaneous in-line force by the instantaneous velocity of the multidisc relative to that of the fluid and integrating over a period of one oscillation cycle as follows:

$$E=\frac{1}{T}\int_0^{T} F(t)\times v(t)d(t) \quad (2)$$

The E_f and E_v values in Fig. 1 can be expressed by the following equations:

$$E_f=(1/2)\rho S_0 C_{df} U_0^3 \quad (3)$$

$$E_v=(2/3\pi)\rho S_0 C_{dv}(a\omega)^3 \quad (4)$$

where C_{df} and C_{dv} are the drag coefficients for the stationary multidisc in a fluid flow and for the vibrating multidisc in a fluid at rest, respectively. The drag coefficients C_{df} and C_{dv} obtained from our experiment are shown in **Tables 2** and **3**. In the range of a/d examined, the value of C_{dv} is almost pro-

Table 1. Experimental conditions

Diameter d	[cm]	6.0
Disc distance L	[cm]	2.4– 9.0
Velocity of fluid flow U_0	[cm/s]	5.0–15.0
Amplitude of oscillation a	[cm]	1.0– 4.0
Frequency of oscillation f	[Hz]	0.5– 1.5
Reynolds number U_0d/ν	[—]	3330–10,000
Reynolds number $a\omega d/\nu$	[—]	5540–16,600
Reynolds number $d^2\omega/\nu$	[—]	16,600–24,900

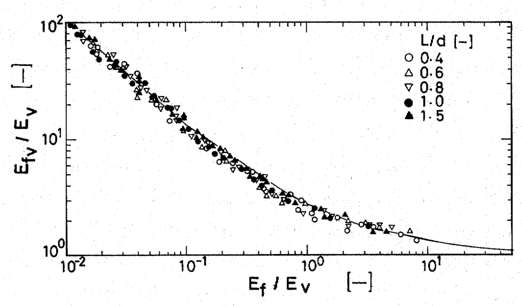

Fig. 1. Relation between E_{fv}/E_f and E_f/E_v: solid line shows Eq. (5)

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Table 2. Drag coefficient for stationary multidisc in a fluid flow, C_{df}

L/d [—]	0.4	0.6	0.8	1.0	1.5
C_{df} [—]	2.6	2.9	3.2	4.9	5.8

Table 3. Drag coefficient for vibrating multidisc in a fluid at rest, C_{dv}

Amplitude a [cm]	Disc distance ratio, L/d [—]				
	0.4	0.6	0.8	1.0	1.5
1.0	14.3	21.5	28.2	35.0	49.5
2.0	8.0	12.0	15.7	18.0	30.1
3.0	5.8	8.8	11.5	14.0	21.5
4.0	4.5	6.8	9.0	11.5	18.0

portional to $-4/5$ power of a/d for every L/d.

The solid line in Fig. 1 shows the following equation for the single disc obtained in a previous experiment[2];

$$E_{fv}^{2/3}=E_f^{2/3}+E_v^{2/3} \tag{5}$$

Although there is some difference between the fluid force on the single disc and that on the multidisc, the correlation between the energy dissipation ratio for the multidisc agrees well with that for the single disc in the range of L/d examined. The range of deviation between the present data and Eq. (2) is just over ± 15 percent.

The drag coefficient for the single disc in a fluid flow is given by the following equation:

$$C_d=\mathscr{F}(C_{df},\ C_{dv},\ U_0/a\omega) \tag{6}$$

Based on this relation, the drag coefficients for the oscillating multidisc in a fluid flow, C_{d5}, for $a/d=0.5$ are shown against the ratio of fluid velocity to maximum oscillation velocity, $U_0/a\omega$, in **Fig. 2.** It would be expected that the fluid drag acting on the multidisc decreases with decreasing distance between the discs, because the interaction between the discs would work as a dumping action. If the distance is large enough compared to disc diameter, the effect of L/d on fluid drag is negligible. Hence, the fluid drag acting on the multidisc would be equal to the sum total of each fluid drag acting on the five single discs. Curves drawn in Fig. 2 are calculated from Eq. (15) in our previous paper[2] with the C_{df} and C_{dv} values shown in Tables 2 and 3. Also, five times the drag coefficient of the singledisc is shown in Fig. 2. When $U_0/a\omega$ is larger than 0.6, agreement between the calculated values and the experimental ones are almost within ± 20 percent. When $U_0/a\omega$ is less than 0.6, however, the values are not close. In such a case, the present data show higher values than the values

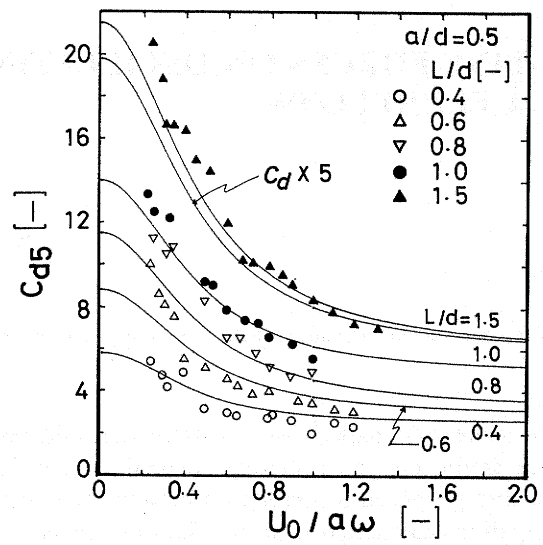

Fig. 2. Variation of drag coefficient with $U_0/a\omega$

predicted from Eq. (15). The maximum deviation from the value calculated with Eq. (15) is 53 percent in the range of $U_0/a\omega$ examined.

It is clear from Fig. 2 that the value of C_{d5} decreases with decreasing L/d and becomes almost five times the value of C_d at $L/d=1.5$. This means that the effect of distance between discs is small at $L/d=1.5$.

As for the other amplitude ratio a/d, the variation of the drag coefficient is similar to that for $a/d=0.5$. Also, when L/d is equal to 1.5, the effect of L/d becomes small in every a/d examined.

Nomenclature

a	= amplitude of oscillation	[m]
C_d	= drag coefficient	[—]
d	= diameter of disc	[—]
E	= time-averaged energy dissipation	[W]
F	= fluid resistance	[N]
L	= distance between discs	[m]
S_0	= projected area of disc	[m^2]
t	= time	[s]
U_0	= velocity of fluid flow	[m/s]
v	= relative velocity of disc to fluid	[m/s]
ρ	= density of fluid	[kg/m^3]
ω	= angular frequency	[Hz]

⟨Subscripts⟩

f	= fluid flow
v	= oscillation
5	= multidisc

Literature Cited

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