MEMOIRS OF THE SCHOOL OF ENGINEERING, OKAYAMA UNIVERSITY, Vol. 8, No.2, December 1973

The Friction Factors of Oscillating Pipe Flows

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(Received November 17, 1973)

Synopsis

In this study, the friction factors of oscillating pipe flows are experimentally investigated. As the oscillating pipe flow, the pendulation of water column in the special vertical U-tube, which has about the 2 m long horizontal straight foot pipe, is utilized.

The results of experiments show that the momentary friction factors in the accelerating state are smaller and in the decelerating state are larger than that in steady state for each Reynolds numbers.

1. Introduction

In regard to the friction factors of the unsteady pipe flow, the theoretical analysis has been established for the laminar flow.[1)2)] But for the turbulent flow, it is difficult to develop the theoretical analysis, and so there is only way by the experimental study.

In the last report,[3)] the experimental study for the pulsating flow superposed on the steady turbulent flow has been done. In this report, for the oscillating pipe flow the experimental study is done, using the pendulation of water column in the special vertical U-tube. The friction factor is measured up to the Reynolds number

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about 3×10^4 and the acceleration about $\pm 0.15\,g$.

2. Experimental Apparatus and Procedure

Fig. 1 shows the outline sketch of experimental apparatus. The special U-tube is put together with the acrylic plastic tube of inner diameter 30 mm, and has the horizontal straight pipe as the foot part. The foot pipe is about 2.6 m long and constitutes the test section. The test section has the pressure taps A and B, and the distance between them is $\ell = 2$ m. The using pressure transducers are semi-conductor strain-gage type (TOYODA Machine Works, PMS-5), and these out-puts are amplified by D.C. amplifier and mixing amplifier (TOYODA Machine Works, THA-III and TMA-I), and connected to the in-put terminal of the recorder.

The one vertical pipe, at the top position, has the ball balve and the inlet valve to supply the compressed air. The other vertical pipe has the inner insulated electrode and the outer shield of the steel pipe. The electric capacity between the inner electrode and the outer shield is used as the water level transducer. The change of electric capacity is detected by the FM type converter and amplifier (DISA Elektronik, 51B00 and 51B02) and terminated to the recorder.

Water is filled into the U-tube through the head tank, up to the about middle level in the vertical pipe. At the first step, the ball valve is closed and through the inlet valve compressed air is added to push down the water level to the settled position. At the second step, the recorder is started and then the ball valve is instantaneously opened. The water column oscillates and on the paper of the servo recorder (WATANABE SOKKI SR-501), the pressure difference between A and B and

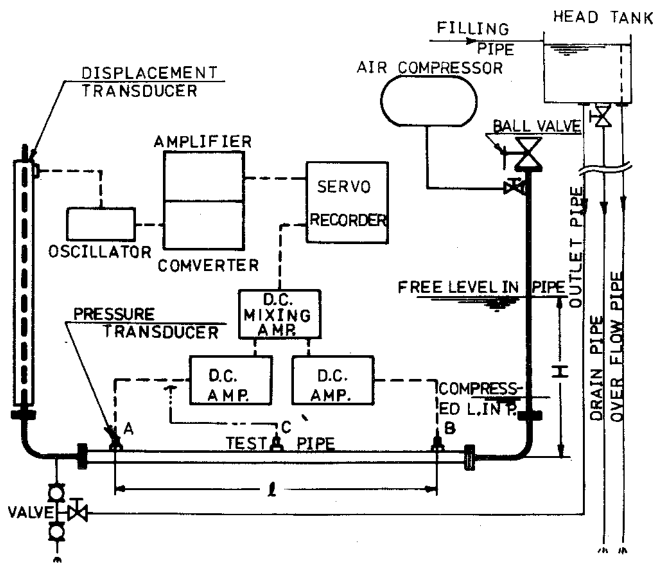


Fig. 1 Outline sketch of experimental apparatus.

the water level displacement are recorded with the time marker. The recorded curves are numerically analysed.

3. Analytical Studies

The equation of motion for the unsteady flow through the straight circular pipe is expressed by

$$\frac{\partial w}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial s} - \lambda \frac{w}{2d}|w| , \tag{1}$$

where w is the sectional mean velocity, p is the pressure, ρ is the density of water, d is the inside diameter of the pipe, λ is the friction factor, s is the distance along the pipe and t is the time.

Integrating the equation (1) from $s=0$ to $s=\ell$,

$$\Delta p = \rho\ell\frac{\partial w}{\partial t} + \lambda\frac{\ell}{d}\frac{\rho}{2}w|w| = \rho\ell a + \lambda\frac{\ell}{d}\frac{\rho}{2}w|w| , \tag{2}$$

where ℓ is the distance between two pressure taps, Δp is the pressure loss and a is the sectional mean acceleration of water. If the value of the friction factor λ is considered as follows,

$$\lambda = \lambda_s + \lambda_t , \tag{3}$$

equation (2) becomes as follows,

$$\Delta p - \rho\ell a = \lambda_s\frac{\ell}{d}\frac{\rho}{2}w|w| + \lambda_t\frac{\ell}{d}\frac{\rho}{2}w|w| . \tag{4}$$

The first term of right side of equation (4) means pressure loss by friction when the flow is regarded as steady state, and the second term means the additional pressure loss occuring from the condition when the flow is unsteady.

4. Experimental Results and Discussion

Fig. 2 shows the detail of the water level displacement transducer. The electric capacity between the electrodes changes with the water level displacement, as shown in Fig. 3, where abscissa shows the displacement and ordinate the capacity. To make the capacity fit for the turning plug, two condensers are connected in parallel and series. The all-over characteristics are shown in Fig. 4, where ordinate shows the out put of the amplifier.

The one of the recorded curves is shown in Fig. 5. In the figure, the upper

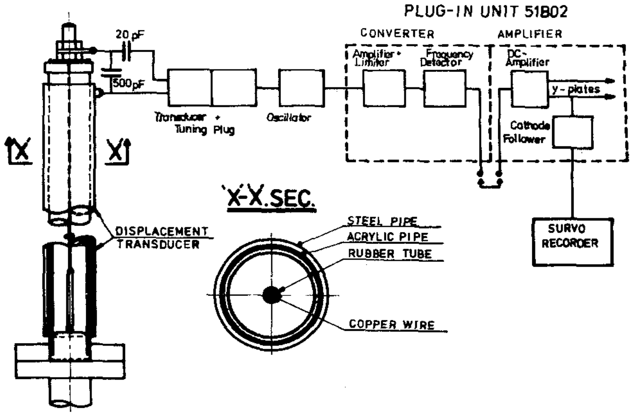


Fig. 2 Detail of the water level transducer.

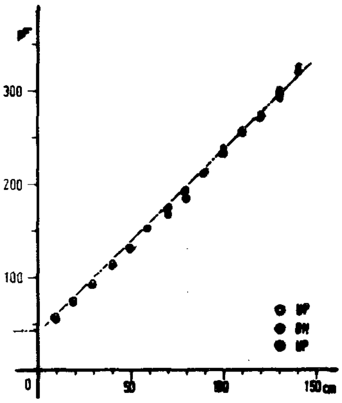


Fig. 3 Electric capacity versus the water level displacement.

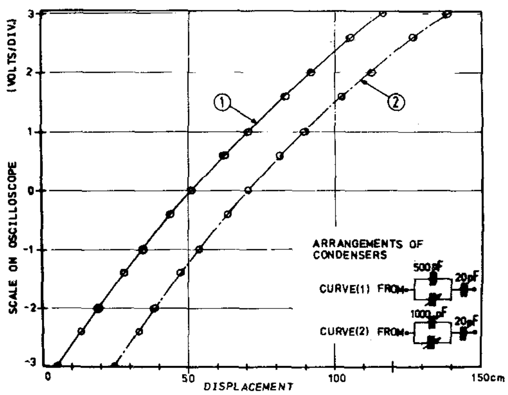


Fig. 4 Over-all characteristic of the transducer.

curve shows the water level displacement, the lower the pressure difference (A - B) and the middle the time marker.

The relation between the deflection of the recorder pen on the chart and the water level displacement is shown in Fig. 6, where abscissa shows the displacement and ordinate the deflection. Farther the relation between the deflection of the pen and the pressure difference (A - B) is shown in Fig. 7, where abscissa shows the pressure difference and ordinate the deflection.

Thus from the recorded curves, the changes of the water level displacement y and pressure difference Δp versus the elapsed time are read out.

The displacements of the water level versus the time can be expressed as follows,

$$y = y_0 \exp(ax^3 + bx^2 + cx) \cos(qx + \phi) , \qquad (5)$$

where y_0 is the initial displacement, x is the time and a, b, c, q and ϕ are constants decided from the data. Differentiating equation (5) with the time x, the sectional mean velocity w and accerelation α are obtained as follows,

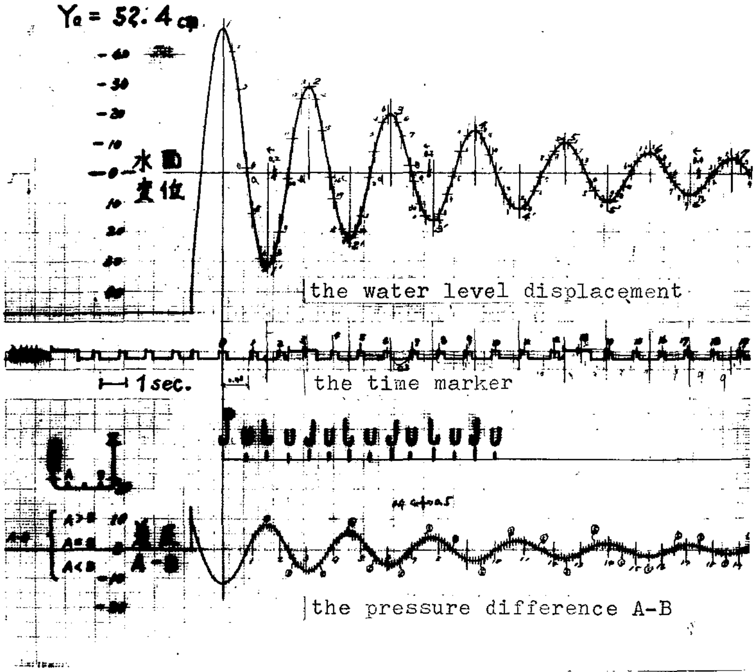


Fig. 5 The one of the recorded curves.

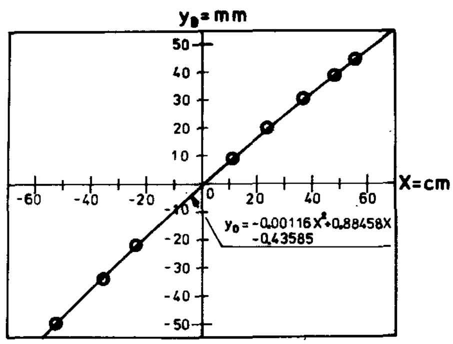


Fig. 6 The deflection (y_p) of the recorder pen versus the water level displacement (x).

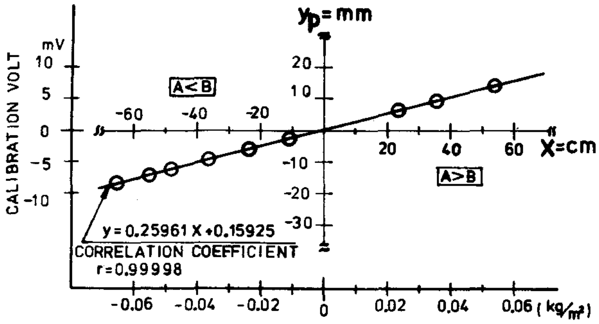


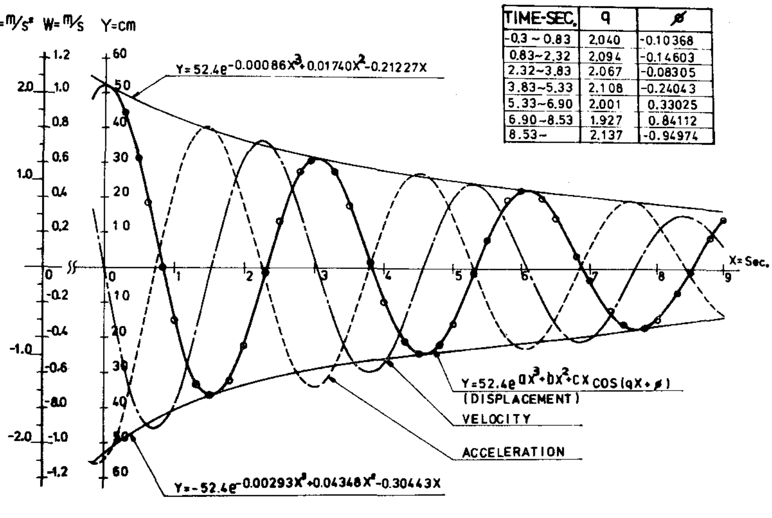
Fig. 7 The deflection (y_p) of the recorder pen versus the pressure difference (A - B) (x).

$$w = \frac{dy}{dx} = y_0 \exp(ax^3 + bx^2 + cx)$$
$$\{(3ax^2 + 2bx + c)\cos(qx + \phi) - q\sin(qx + \phi)\}, \qquad (6)$$

and

$$a = \frac{d^2y}{dx^2} = y_0 \exp(ax^3 + bx^2 + cx)$$
$$[\{(3ax^2 + 2bx + c)^2 + (6ax + 2b) - q^2\}\cos(qx + \phi)$$
$$-2q(3ax^2 + 2bx + c)\sin(qx + \phi)]. \qquad (7)$$

The calculated results by YHP 9100A Calculator and 9125B Plooter for the data of Fig. 5, are shown in Fig. 8.



TIME-SEC.	q	ø
-0.3 ~ 0.83	2.040	-0.10368
0.83~2.32	2.094	-0.14603
2.32~3.83	2.067	-0.08305
3.83~5.33	2.108	-0.24043
5.33~6.90	2.001	0.33025
6.90~8.53	1.927	0.84112
8.53~	2.137	-0.94974

Fig. 8 Calculated displacement y, velocity w and acceleration a versus the time x.

Farther, calculating the pressure loss due to the acceleration $\rho l a$, the friction factor λ is calculated from equation (2). On the other hand, the friction factor λ_s of the used pipe for steady state is examined by the another apparatus and it is ascertained that Blasius formula is available. Fig. 9 shows these pressure losses versus the time. The friction factor λ_t according to equation (3), is shown in Fig. 10. Figs. 9 and 10 are available for the data of Fig. 5, and in Fig. 10 the friction factors for the state in the neighborhood of the maximum acceleration and so the small velocity are dropped out, for the reason that the large error may be contained in the values of friction factor on account of the expression formula for it.

Analysing the other data, the same results are obtained.

As the results, it is recognized qualitatively that for the first and second period, the friction factors λ_t are negative in the accelerating state and positive in the decelerating state, i.e. the momentary friction factors λ are smaller in the accelerating state and larger in the decelerating state than that in steady state for each velocities. During these periods the maximum velocity is about 1.0 m/sec., i.e. Reynolds number $R = wd/\nu$ (ν is the kinematic viscosity of water.) is 3×10^4 , and the maximum acceleration is about ± 1.5 m/sec^2., i.e. $\pm 0.15\, g$ (g is gravitational acceleration.). But nothing is obtained about the quantitative relation for λ_t versus acceleration and Reynolds number. Farther for the succeeding periods the convincing results are not obtained even qualitatively. It is surmised that these facts will be due to the defects of the test section and the water level displacement transducer.

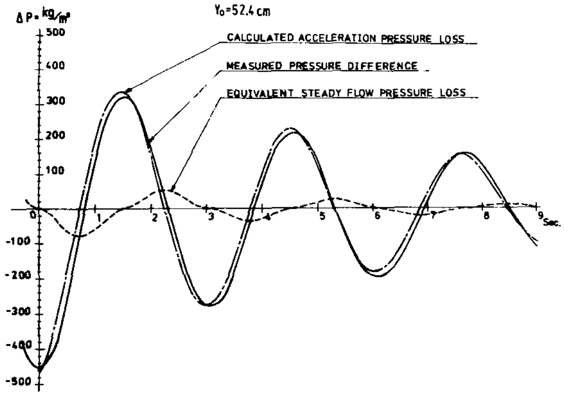


Fig. 9 The measured and calculated pressure losses versus the time.

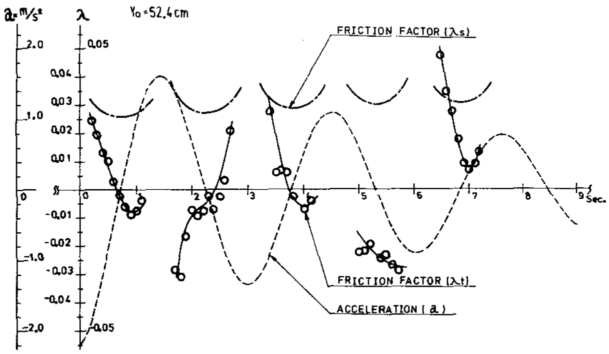


Fig. 10 The acceleration a and friction factor λ_t versus the time.

5. Conclusion

Using the pendulation of water column in the special U-tube, the friction factors for the oscillating pipe flows are examined.

Qualitatively the momentary friction factors in the accelerating state are smaller and in the decelerating state are larger than that in the steady state, in the Reynolds number range from 1×10^4 to 3×10^4 and the acceleration range $\pm 0.15 g$.

References

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