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Flowmeter for large-scale pipes

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Abstract

This paper studied a new type of flowmeter, the bypass flowmeter. It is suitable for large-scale pipes. The principle of bypass flowmeter is studied by analyzing flowing in parallel pipes and carrying out experiments at a modified performance test system for centrifugal pumps. The study results showed that the flowrate ratio between the main pipe and the bypass pipe is determined by the geometric structures of pipes and the flowing states in the pipes. The flowrate ratio varies greatly when the Reynolds numbers are relatively lower both in the main pipe and the bypass pipe. The flowrate ratio keeps constant when the Reynolds number in the main pipe is larger than 120000. The head loss becomes smaller when the bypass pipe is connected to the main pipe. The percentage of head loss decrease is from 7.64% to 9.34%. The results indicate that bypass flowmeter is suitable for flowrate measuring in large scale pipes. It will not cause additional head loss to the flow.

Keywords: bypass; flowrate; flowmeter; large scale pipe

1. Introduction

Flowrate is an important parameter for measuring and controlling in industrial process. There are two ways for measuring flowrate, direct measurement and indirect measurement. The direct measurement is to measure the total volume or mass within a certain interval of time; while indirect measurement is to measure the parameters that are related to the flowrate. The latter is often applied in engineering.

Although there are various kinds of flowmeters, the differential-pressure flowmeter (DPF) is the most commonly used one. For flowing in pipes with large diameters, measurement of flowrate is not an easy job.

Generally speaking, the flowrate measuring in large scale pipes has the following characteristics:

(1) It is hard to ensure the measuring accuracy. Small error will be amplified due to large scale.

(2) Measuring instrument may become too heavy.

(3) Maintenance of the instrument is also very difficult because most of the large pipelines are underground.

(4) Measuring signal is often not strong enough for the velocity and pressure in large pipes are usually low.

Therefore, most of the commonly used flowmeters are not suitable for large scale pipes, such as Venturi flowmeter, orifice-plate flowmeter, electromagnetic flowmeter, and so on.

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Many researchers have studied the application of a bypass pipe used in the measurement of flowrate [1] [2] [3]. Based on the flowing performance in parallel pipes, this paper will study the principle of the bypass flowmeter. The bypass flowmeter:

(1) is simple in structure;
(2) will not cause any additional pressure loss;
(3) is easy for installation and maintenance;
(4) has a higher accuracy.

2. Principle of bypass flowmeter

In order to deduce the relationship between flowrates in the main pipe and the bypass pipe, a simplified model is given in Fig.1.

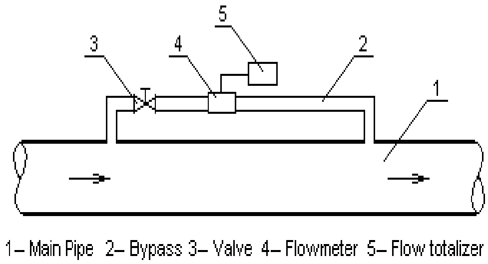


Fig. 1。 Diagram of the by-pass flowmeter

It can be simplified as a parallel pipe consisting of two pipes, a main pipe and a bypass pipe. Therefore, we have

$$q = q_m + q_b \tag{1}$$

$$h_{fm} = h_{wb} \tag{2}$$

where, the subscripts *m* and *b* represent the main pipe and the bypass pipe. The head loss in both pipes can be expressed as

$$h_{fm} = \lambda_m \frac{L_m}{d_m} \frac{v_m^2}{2g} \tag{3}$$

$$h_{wb} = (\lambda_b \frac{L_b}{d_b} + \Sigma\zeta_b) \frac{v_b^2}{2g} \tag{4}$$

From (1)-(4), it can be obtained

$$\frac{v_m}{v_b} = \left(\frac{\lambda_b L_b / d_b + \Sigma\zeta_b}{\lambda_m L_m / d_m} \right)^{0.5} \tag{5}$$

The flowrate ratio *k* between the main pipe and the bypass pipe is

$$k = \frac{q_m}{q_b} = \frac{d_m^2}{d_b^2}\left(\frac{\lambda_b L_b / d_b + \Sigma\zeta_b}{\lambda_m L_m / d_m}\right)^{0.5} \tag{6}$$

The original flowrate can be obtained by

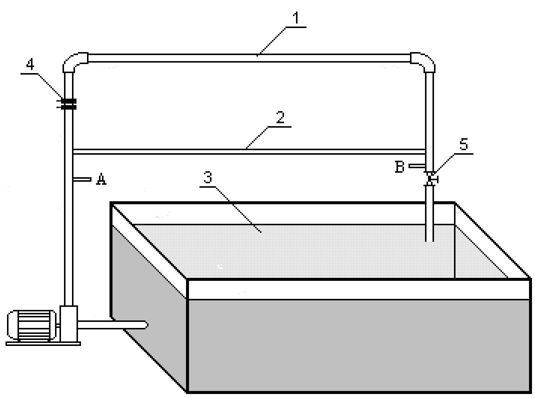
$$q = (1+k)q_b = \left\{1 + \frac{d_m^2}{d_b^2}\left(\frac{\lambda_b L_b / d_b + \Sigma\zeta_b}{\lambda_m L_m / d_m}\right)^{0.5}\right\} q_b \tag{7}$$

From equation (7), the total flowrate in the pipe can be calculated by measuring the flowrate in the bypass pipe only.

However, the flowrate ratio k is influenced by various factors. As can be seen from equation (6), these factors include diameter ratio of the main pipe and bypass pipe, lengths of both pipes, friction factors of both pipes, and loss coefficient of the bypass pipe. Some parameters, such as diameter ratio, length of pipes and loss coefficient, are determined by the geometric structure; while friction factors of both pipes vary with flowing conditions. Fortunately, the friction factor keeps constant when the Reynolds number is large enough. The friction factor does not change greatly even when the Reynolds number is between 10^4 and 10^5.

3. Experimental results and discussion

An experimental system was set up by modifying a performance test system for centrifugal pump, as shown in Fig.2. The flowrate through the main pipe is measured by an orifice-plate flowmeter installed in series in the main pipe; and the total flowrate is measured by weighing the water flowing out within a certain time interval. The total flowrate can be changed by adjusting the valve opening position. The flowrate through the bypass pipe can be obtained from the difference between the two flowrates.



1—Main pipe 2—Bypass pipe 3—Tank 4—Orifice-plate flowmeter 5—Valve

Fig. 2. Diagram of test system

In our experiments, two bypass pipes with diameters of 14mm and 12mm are used. The diameter of the main pipe is 50mm. Table 1 and 2 give the experimental results for flowrate ratio.

Table 1. Flowrate ratio for the bypass pipe with diameter of 14mm

No.	Total flowrate ($10^{-5}m^3/s$)	Flowrate in main pipe($10^{-5}m^3/s$)	Reynolds number in main pipe	Flowrate in bypass pipe ($10^{-5}m^3/s$)	Reynolds number in bypass pipe	Flowrate ration
1	54.94	52.8	14995	2.14	2171	24.67
2	88.73	85.1	24168	3.63	3682	23.44
3	113.37	108.3	30757	5.07	5142	21.36
4	292.1	278.4	79066	13.7	13896	20.32
5	323.8	308.8	87699	15	15214	20.59
6	353.9	337	95708	16.9	17141	19.94
7	398.06	379.1	107664	18.96	19231	19.99
8	458.53	436.6	123994	21.93	22243	19.91
9	513.78	489.2	138933	24.58	24931	19.90
10	538.45	512.7	145607	25.75	26118	19.91

Table 2. Flowrate ratio for the bypass pipe with diameter of 12 mm

No.	Total flowrate ($10^{-5}m^3/s$)	Flowrate in main pipe ($10^{-5}m^3/s$)	Reynolds number in main pipe	Flowrate in bypass pipe ($10^{-5}m^3/s$)	Reynolds number in bypass pipe	Flowrate ration
1	54.15	52.7	14967	1.45	1716	36.34
2	56.8	55.2	15677	1.6	1893	34.50
3	106.57	103.3	29337	3.27	3869	31.59
4	298.12	288.7	81991	9.42	11147	30.65
5	318.17	307.6	87358	10.57	12508	29.10
6	353.33	341.5	96986	11.83	13999	28.87
7	400.82	387.3	109993	13.52	15999	28.65
8	447.62	432.5	122830	15.12	17892	28.60
9	504.63	487.6	138478	17.03	20152	28.63
10	528.65	510.8	145067	17.85	21123	28.62

From Table 1 and 2, it could be clearly seen that the flowrate ratio varies greatly when the Reynolds numbers are relatively lower both in the main pipe and bypass pipe. With the increasing of the Reynolds number, the flowrate ratio becomes stable. It keeps constant when the Reynolds number is big enough. It is found from the experimental results that the flowrate ratio keeps constant when the Reynolds number in the main pipe is larger than 120000.

Table 3 gives the experimental results for head loss between the points A and B in Fig.2.

Table 3. Head loss for the bypass pipe with diameter of 14mm

No.	Total flowrate ($10^{-5}m^3/s$)	Flowrate in main pipe ($10^{-5}m^3/s$)	Flowrate in bypass pipe ($10^{-5}m^3/s$)	Head loss between A and B (mmH_2O)	Percentage in Head loss decrease
1	54.94	52.8	2.14	95	7.64%
		54.94	0	103	
2	88.73	85.1	3.63	100	8.01%
		88.73	0	109	
3	113.37	108.3	5.07	115	8.74%
		113.37	0	126	

4	292.1	278.4	13.7	120	9.16%
		292.1	0	132	
5	323.8	308.8	15	150	9.05%
		323.8	0	165	
6	353.9	337	16.9	180	9.32%
		353.9	0	199	
7	398.06	379.1	18.96	225	9.30%
		398.06	0	248	
8	458.53	436.6	21.93	305	9.34%
		458.53	0	336	
9	513.78	489.2	24.58	390	9.34%
		513.78	0	430	
10	538.45	512.7	25.75	430	9.34%
		538.45	0	474	

It can be easily seen from Table 3 that the head loss between the point A and B becomes smaller when the bypass pipe is connected with the main pipe. The percentage of head loss decrease is from 7.64% to 9.34%. The percentage increases with the total flowrate. When a bypass pipe is connected to the main pipe, the flow cross-sectional area becomes larger, and the flow velocity in the main pipe will decrease. It is obvious that the bypass pipe will not cause additional head loss to the system. On the other hand, it reduces the head loss.

4. Conclusions

Based on the flowing performance in parallel pipes, the flowrate in a large-scale main pipe can be determined by measuring the flowrate in the bypass pipe only.

The flowrate ratio between the main pipe and the bypass pipe is influenced by various factors, such as the diameter ratio of the main pipe and bypass pipe, lengths of both pipes, friction factors of both pipes, and loss coefficient of the bypass pipe.

Experimental results showed that the flowrate ratio keeps constant when the Reynolds number in the main pipe is larger than 120000.

The head loss becomes smaller when the bypass pipe is connected to the main pipe. The percentage of head loss decrease is from 7.64% to 9.34%.

The bypass flowmeter is a suitable way for flowrate measuring in large scale pipes.

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