Elliptical Tube Flowmeter

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KEYWORDS

Elliptical Profile Restriction, Oversize Tap, Pressure Lead-pipe, Pressure Loss

ABSTRACT

Elliptical-tube flowmeters are a new type of single-piece differential pressure flowmeter. The compact flowmeter's flow section consist of a fluid inlet and outlet with a restricted elliptical profile, an oversize tap and a small-sized remote seal transducer for measurement of differential pressure. This paper describes the merits of new elliptical-tube flowmeter. Its elliptical profile restriction provides stable measurement of differential pressure, which, combined with an oversize tap and small-sized remote seal transducer, eliminates the need for a pressure lead-pipe. The elliptical profile shape restriction of the outlet provides less pressure loss. This document reports the principle, structure, performance and the results of the field test of the elliptical-tube flowmeter.

INTRODUCTION

In the field of flow measurement, differential pressure flowmeters are the most popular type of flowmeters. This is because their mechanism is simple, and they can be used in various fluids such as liquid, gas, and steam. However, despite their advantages, they have a serious problem with their lead-pipes clogging, which restricts the type of fluids they can measure. According to a breakdown of an investigation of troubles with flowmeters at a certain petrochemical plant, differential pressure flowmeters account for 70 percent of all troubles of which lead-pipe are the leading cause. Other problems are that they can only measure a confined range within narrow limits, and that their pressure loss is larger than the any other flowmeters. They aren't suitable for measurement of slurry or adhesiveness fluid. To make up for their shortcomings, troublesome work is needed, such as cleaning out lead pipes, keeping lead-pipe hot to prevent clogging, and exchanging orifice plates when different ranges need to be measured. Recently, most users have replaced differential pressure flowmeters with the other principle flowmeters, because of its shortcomings.

Differential pressure flowmeters are given official sanction and their advantages are recognized. If they can get over their shortcomings, the demand for differential pressure flowmeters will definitely increase. Elliptical-tube flowmeters were developed to solve shortcomings with differential pressure flowmeters. The concept of elliptical-tube flowmeters is as follows.

- Oversize tap to prevent lead-pipe clogging
- Less pressure loss
- Compact size and simple structure

Differential pressure must be measured in a stable condition. When a tap for the measurement of differential pressure is expanded to avoid clogging, the measurement of differential pressure is easily affected by the extraneous flow. The elliptical-tube flowmeter's flow section has a structure that can solve this problem. It consists of a fluid inlet and outlet with a restricted elliptical profile, oversize taps and a small-sized remote seal transducer for measurement of differential pressure. For the stable measurement of differential pressure, the inlet has an elliptical profile restriction, and the oversize taps are placed at the most suitable locations. The elliptical profile restriction of the outlet provides less pressure loss.

PRINCIPLE

1.1 Principle.

The principle of measurement is the same principle as other differential pressure flowmeters, such as orifice, venturi-tube and flow-nozzle. To calculate the amount of flow, the coefficient of discharge, which is the relation between differential pressure and the rate of flow, must be calibrated. The coefficient of discharge in orifice, flow nozzle and the like is approved in various standards. However, the coefficient of discharge in this flowmeters must be acquired uniquely, because the elliptical-tube flowmeter is structured on Yamatake's own terms. A unique coefficient of discharge was acquired by using the actual-flow calibrating apparatus in Yamatake's factory. The coefficient of discharge was examined using various beta-ratios and pipe sizes.

The mass flow is calculated by the following equation (1.1).

$$q_m = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon\,\frac{\pi}{4}\,d^2\sqrt{2\Delta p \rho_1}$$

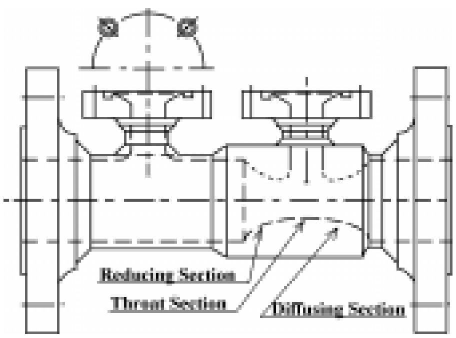
•------- (1.1)

where

qm[kg/sec]	:Mass flow
C	:The coefficient of discharge
β	:Beta-ratio
ε	:The expansion factor of gas
d [mm]	:Throat diameter
⊿P[Pa]	:Differential pressure
ρ 1[kg/m3]	:Density of flowing fluid

1.2 Structure.

Fig1.1, 1.2 shows the outline, and fig1.3, 1.4 shows the external appearances of the elliptical-tube flowmeter. The elliptical-tube flowmeter can mount a small-sized remote seal transducer directly (see Fig.1.1). If a safety valve is needed between the diaphragm base of transducer and the elliptical-tube flowmeter, standard flange types can be selected (see Fig.1.2). The pipe-size of this flowmeters is between 1B and 6B, so beta-ratios are 0.4, 0.5, 0.6, 0.7. Choice of material and flange-rate depends on the measured fluid.



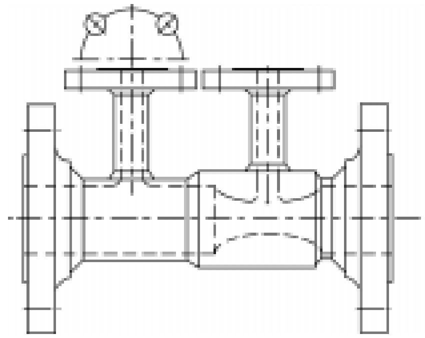


Fig.1.1 Fig.1.2

The Outline of Elliptical-tube Flow meter.

Fig.1.3 Fig.1.4

The external appearance of Elliptical-tube Flow meter.

FLOW SECTION OF ELLIPTICAL-TUBE FLOWMETER

2.1 Oversize tap.

Differential pressure flowmeters have a serious problem with its lead-pipe as described before. Recently, it is said that a remote seal transducer can solve this problem. It is certain that it can eliminate the need for a pressure lead-pipe. However, differential pressure flowmeters need taps and pipes which leads the fluid to the diaphragm to measure its differential pressure. Even if lead pipe is removed, differential pressure flowmeters will have trouble with its taps, because all standards restrict taps to be small. These small size taps will clog easily. To solve this problem completely, oversize taps are adopted to elliptical-tube flowmeters. In the case of 1B, 1-1/2B, the oversize taps have an inner diameter of 10mm, and in the case of 2B-6B, they have an inner diameter of 14mm.

2.2 Optimum of the location of oversize taps.

Differential pressure must be measured in a steady condition to accurately calculate the amount of flow. In front of and behind the reducing section, the pressure of fluid changes. For this reason, taps are restricted to a small size to avoid measuring differential pressure affected by the extraneous flow. If the oversize taps are placed where a pressure of fluid is unstable, the transducer can not accurately measure differential pressure for the calculation of the amount of flow. It is necessary that the oversize tap should be placed where a pressure of fluid is stable across the whole diameter of the oversize tap.

As a general rule, the following two locations are considered as the location of the upstream pressure tap.

- The Corner of the reducing section
- A short distance in front of the entrance of reducing section

The former is not suitable for the oversize tap, because the fluid pressure is unstable near the corner of the reducing section. To measure a stable fluid pressure, the oversize tap must be kept at a certain distance away from the entrance of reducing section. Then a stable fluid pressure is easily measured. However, the location of the upstream pressure tap should be close to the reducing section as much as possible, because one of the concepts of this flowmeters is to be compact in size. Therefore the shortest distance from the reducing section where a stable fluid pressure can be measured was researched.

In the case of the downstream pressure tap, three locations can be considered.

- Corner of the diffusing section
- Some distance after the flow section
- Throat part of the flow section

Fluid pressure is too unstable behind the diffusing section. To measure stable pressure, the oversize tap is placed at a certain distance from the flow section on the downstream side. However, sufficient differential pressure can not be measured at this location. So it should be at a place where the pressure is the minimum value. On the other hand, fluid pressure at the throat part is stable enough and a sufficient differential pressure can be measured. The optimum length of the throat part and the optimum location of the oversize tap in the throat part were determined from numerous experiments.

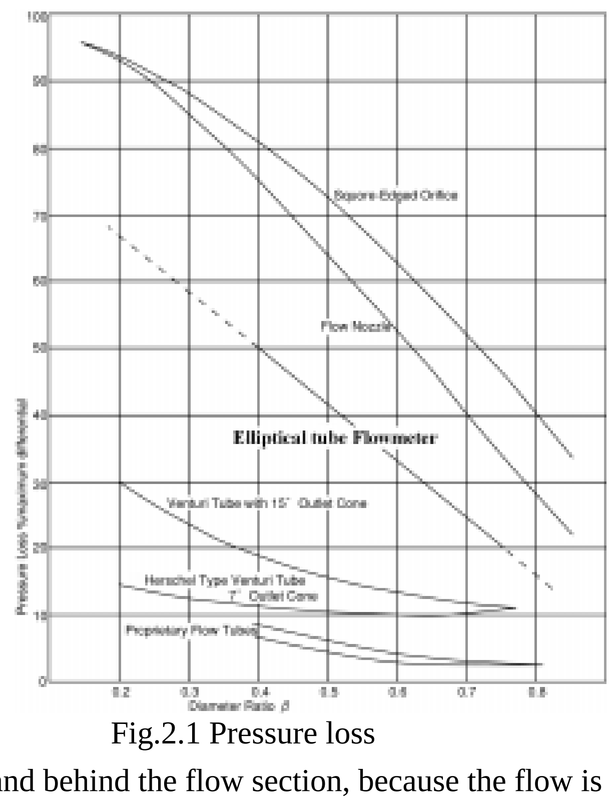


Fig.2.1 Pressure loss

2.3 Elliptical profile.

The new flow section should satisfy the following conditions.

- Stable measurement of differential pressure
- Less pressure loss
- Short length of flow section

In the case of the orifice, a fluid is fluctuated in front of and behind the flow section, because the flow is reduced suddenly at its reducing section. With the increase of the amount of flow, differential pressure is also fluctuated. On the other hand, stable pressure is measured from the venturi-tube and flow-nozzle, because their reducing section is reduced gradually, in order for the flow not to swirl (see Par.3.1). Moreover, venturi-tube and flow-nozzle with diffusing pipes are known to have lesser pressure loss than an orifice at its flow section. However, these flow sections have very long length.

An elliptical profile of a fluid inlet and outlet was adopted for the following reasons.

- The Stable differential pressure can be measured
- The pressure loss is little, despite the short length.
- Elliptical surface is given by a numerical formula

The longer the diffusing section is, the lesser pressure loss is. For elliptical-tube flowmeters, relations between the length of the diffusing section and pressure loss were invested, then the optimum length was decided. The pressure loss of elliptical-tube flowmeters and other flowmeters are shown at Fig.2.1.

FLOW MEASUREMENT BY ELLIPTICAL-TUBE FLOWMETER

This section reports the accuracy, steadiness of output and straight pipe length needed on the upstream side for a reliable pressure measurement.

3.1 Steadiness of output.

Fig.3.1-3.3 shows the output of the elliptical-tube flowmeter, the electromagnetic flowmeter and the orifice flowmeter. The output of electromagnetic flowmeter is shifted by +0.1[V] and orifice’s is shifted by –0.1[V] to be able to better see. Table 3.1 shows the fluid condition and table 3.2 shows the specification of each flowmeter used in the experiment. Fig.3.4 shows the experimental apparatus. Fig.3.5 shows the unsteadiness of each flowmeter’s output. The elliptical-tube flowmeter is shown to be the steadiest of the three at each flow rate. When the flow rate is 90%, there are striking differences between the output of the elliptical-tube flowmeter and the orifice or the electromagnetic flowmeter. This is due to the elliptical profile of reducing section and the optimum location of each oversize tap.

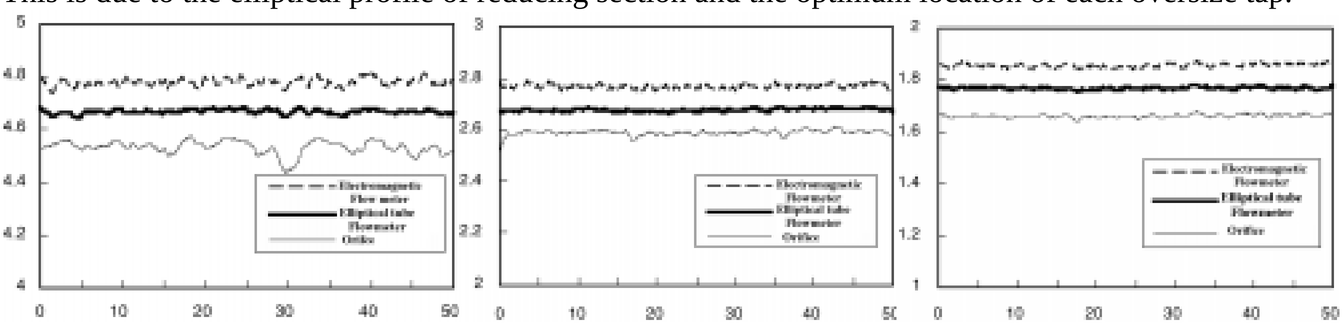


Fig.3.1 Flow rate 90%. Fig.3.2 Flow rate 40%. Fig.3.3 Flow rate 20%

Fig.3.1-3.3 Output of Flow

Table 3.1 Fluid Condition	
Fluid	Water
Temp.	25 [degrees C]
Pres.	100 [kPa]
Density	996.91 [kgf/m^{3}]
Viscosity	8.94 [mPa S]

Table 3.2 Flowmeter specification

Type	Electromagnetic Flowmeter	Orifice	Elliptical tube Flowmeter
Pipe size	1B	1B	1B
Beta-ratio	-	0.51	0.4
Range	70[l/min]	69[kPa]	69[kPa]
Output type	Linear	Square root	

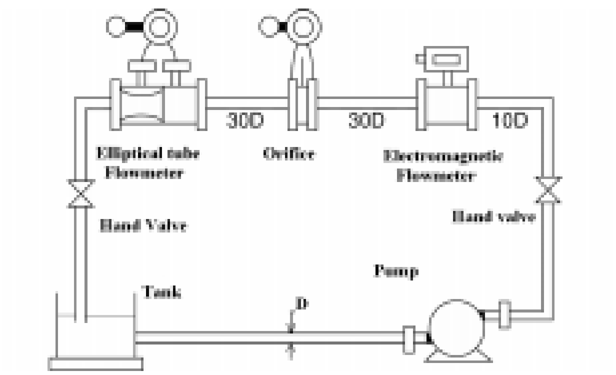


Fig.3.4 Apparatus

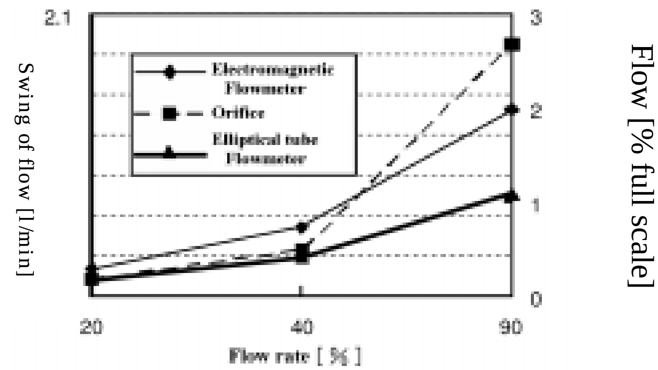


Fig.3.5 Unsteadiness of flow

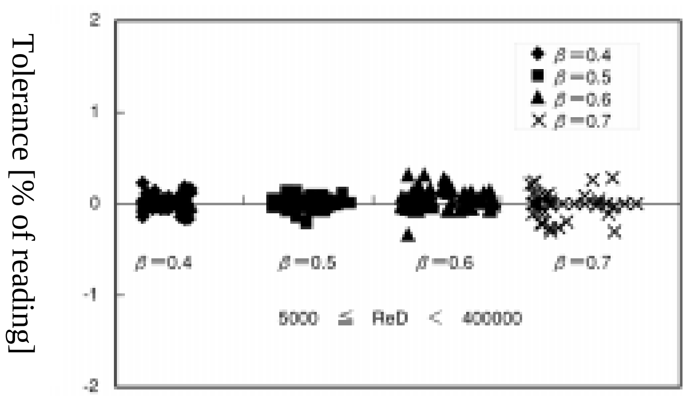


Fig.3.6 Results of evaluation

3.2 Evaluation.

The standard accuracy of elliptical-tube flowmeters is based on Yamatake's actual-flow calibrating apparatus, which is operated under a standard conditioning environment. Besides the test instruments, many elliptical-tube flowmeters made for the field evaluation were tested whether they would satisfy the standard accuracy. The pipe size to be evaluated was between 1inch and 6inch, and the beta-ratio was 0.4,0.5,0.6,0.7. Fig. 3.6 shows the results of evaluation.

According to the results of the evaluation, output from the flow section of elliptical-tube flowmeters is within plus or minus 0.2% reading. As a point of notice, these errors do not include the transition of the coefficient of discharge, which is influenced by Reynolds number.

3.3 Straight pipe length on the upstream side.

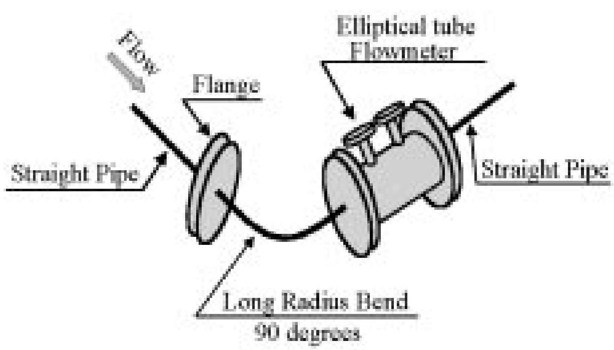
Differential pressure flowmeters need a long distance of straight pipe length on the upstream side to measure a stable differential pressure. Elliptical-tube flowmeters was examined how the straight pipe length on the upstream side influences the accuracy. The test instruments are as follows.

- Pipe diameter size : 50mm
- Beta-ratio : 0.4, 0.5, 0.6, 0.7

This experiment was done to compare the standard condition, where straight pipe length on the upstream side was 1000mm, in the two cases of Fig.3.7, 3.8. Elliptical-tube flowmeters was fitted on same plane against long radius bends (Fig.3.7) and in different planes against two long radius bends (Fig.3.8). Differential pressure was measured from the three directions every 90 degrees. The result is shown in Table 3.3.

Table 3.3 Tolerance

			Beta-ratio			
			0.4	0.5	0.6	0.7
Tolerance [%]	Case1	Direction1	-0.068	-0.172	0.117	0.776
		Direction2	-0.009	-0.356	-0.177	0.623
		Direction3	-0.157	-0.541	-0.508	-0.075
	Case2		-0.140	0.099	0.090	0.237



• • •Fig.3.7 Fittings in same planes (case1)

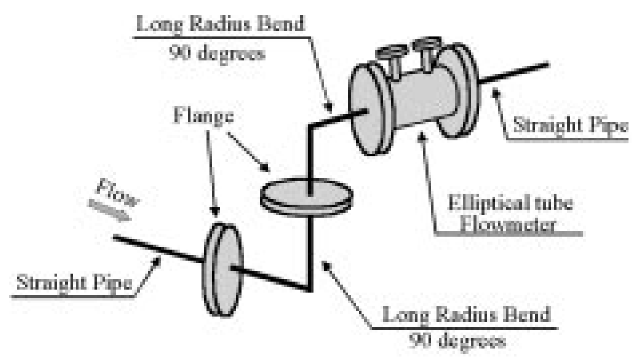


Fig.3.8 Fittings in different planes (case2)

The additional tolerance of plus or minus 0.5 % was applied to elliptical-tube flowmeters. However, the Pipe-Reynolds number was 160,000 or less at this experiment. More experiments are to be done to examine the Pipe-Reynolds number over a wider range.

FIELD TEST RESULTS

The elliptical-tube flowmeter were made as a proposal to solve troubles with flow measurement, and tested in the actual field. This section reports the typical examples.

4.1 Petrochemical plant
<Fluid> Slurry
<Trouble>
Vane flowmeter had been used at this plant. Maintenance was needed frequently, because of a solid adhering to its movable part.
<Proposal>
The measurement by means of the elliptical-tube flowmeter with oversize taps and a small-sized remote seal transducer was proposed to this plant for the purpose of decreasing the frequency of maintenance.
<Result>
At first, the oversize taps was turned to the vertical upward direction to avoid the clogging of oversize taps. The direction was changed to the horizontal direction to remove the error factor of zero-shift after one month. It was expected that oversize taps would clog, but there has been no trouble with oversize taps for a year. On the other hand, the flow is so low that differential pressure is 0.4 [kPa] under normal conditions. However, the elliptical-tube flowmeter still indicates a steady output.

4.2 Chemical plant
<Fluid> Steam
<Trouble>
This user considered using a vortex flowmeter. However, the vortex flowmeter did not have the ability to measure the wanted wide range to be wanted. Moreover, this user also wanted less pressure loss.
<Proposal>
It was proposed that the elliptical-tube flowmeter could measure a low flow and its pressure loss was 40% less than an orifice. As the result of consideration, on the other hand, it was realized that the accuracy was influenced by the coefficient of expansion, when the amount of flow changes. It was also proposed to install a function to correct this factor in the transducer.
<Result>
This user thinks highly of the elliptical-tube flowmeter, because of the accuracy and steadiness of output and its compact equipment.

4.3 Steelworks
<Fluid> Water
<Trouble>
Gear-type flowmeter had been used at this steelworks. Maintenance was needed frequently, because of the biting of its gear part. When the flow changes suddenly, its gear part had a trouble of biting.
<Proposal>
It was proposed that the elliptical-tube flowmeter eliminated the need for a pressure lead-pipe and responded smoothly to the change of flow. It was also proposed that this flowmeter was harder to break, because it did not have the any movable parts.
<Result>
This user thinks highly of the elliptical-tube flowmeter, because of the accuracy and steadiness of output and its compact equipment.