

The Experimental Study and Uncertainty Analysis on the Double Turbine Mass Flowmeter with the Corrective Property for Velocity Distribution

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[Abstract] This paper presents an experimental test results on the double turbine mass flowmeter with the corrective property of liquid velocity distribution. Further analysis on its uncertainty has been conducted accordingly.

Introduction

This paper proposes a new type of mass flowmeter based on the momentum principle of double turbines and of magnetic induction. Its basic structure is illustrated in figure 1 at blow. Inside the flow meter, there are two turbines with different angles of vanes connected by a helical twisting spring. According to the flow momentum theory, the phase difference between the vanes of two turbines has the direct proportion with the mass flow rate. The two magnetic sensitive sensors detect the signal from two vanes of each turbine are installed with a small magnet, the sensors can output two pulse signals by the micro vibration of thin metal along with the vane rotation^{<1>}.

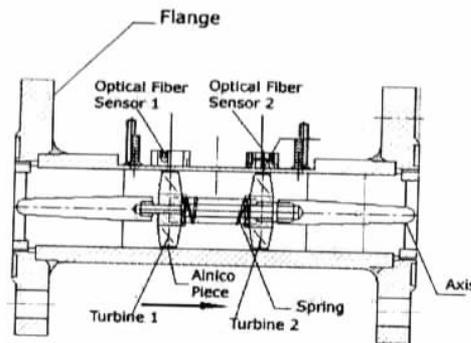


Fig. 1. The instruction illustration of double turbine mass flowmeter

By way of the corrective property of liquid velocity distribution, the theoretical analysis traditionally were set up by the momentum torque and boundary-layer in turbo-machinery and one dimension laminar flow state^{<1>}.

$$\Delta t = \frac{K_0 r D n}{2 E a^3 b \tan \beta_1} \left\{ N \int_{r_h}^{r_l} r S (\tan \beta_2 - \tan \beta_1) dr - N' \int_{r_h}^{r_l} r' S' \{ (\tan \beta_2' + \tan \phi_{sr2}) - (\tan \beta_1' + \tan \phi_{sr1}) \} dr' \right\} q_m \quad (1)$$

In the formula: D is diameter of the spring coils, n denotes the number of coils, E is Young's modulus of the spring material, K_0 is constant coefficient, a is shorter side, b is longer side, β_1 and β_2 are axial angles with import/exit ports, $\phi_{s\gamma}$ is the angle between flow rate of van and its axis, γ is the exit angle, $S = 2\pi r / N$, N is the numbers of blades, q_m is Mass flow. Δt is the phasic time-lag between two turbine vanes.

$$\text{If } k' = \frac{K_0 r D n}{2 E a^3 b \tan \beta_1} \left\{ N \int_{r_h}^{r_h'} S(\tan \beta_2 - \tan \beta_1) dr - N' \int_{r_h}^{r_h'} r' S' \{ (\tan \beta_2' + \tan \phi_{sr2}) - (\tan \beta_1' + \tan \phi_{sr1}) \} dr' \right\}$$

The formula (1) can be expressed as:

$$\Delta t = K q_m \quad \text{or} \quad q_m = K' \Delta t \quad (2)$$

the phasic time lag between two blades has showed linear relationship with mass flow. The flow coefficient $K(=1/K')$ is a geometrically linear parameter with the reliance on the double turbines and its spring.

In this paper, on the basis of constructed sample machine and established math model, the experimental test study of evaluating flow property and its uncertainty analysis have been conducted.

1. The Verifying Method for Double Turbine Mass Flowmeter

In our study, with the utilization of standard Prover and densimeter as standard equipment, the dynamic testing methods is set up among Prover to densimeter on line – master flowmeter to mass flowmeter. This method can provide a solution for measuring the mass flowmeters under the circumstance of unstable flow and density. The master flowmeter, being a volume flow standard meter, is connected between Prover and the flowmeter to be tested. First the Prover is turned on to calibrate the master flowmeter. And then The verification toward mass flowmeter will be conducted immediately by use of master meters and densimeter.

In order to determine the flow range of sample flowmeter, 10 testing points were selected. On the purpose of understanding the property of sample flowmeter at the low flow, the lowest testing point is lower than its lowest flow limit designed in principle for the sample flowmeter. So does for the highest flow testing point selection.

According to the measurement procedures, it is required to test 6 times at each testing point. During the testing process, with every adjustment of each flow point, the test will not started until the pressure, temperature and flow are stabilized.

2. Experimental data and its processing

The sample mass flowmeter property was experimented with the jet fuel. The flow range is $4.0 \sim 40.0 \times 10^3 \text{ kg / h}$. The experimental results are showed in Fig 1 and Fig. 3.

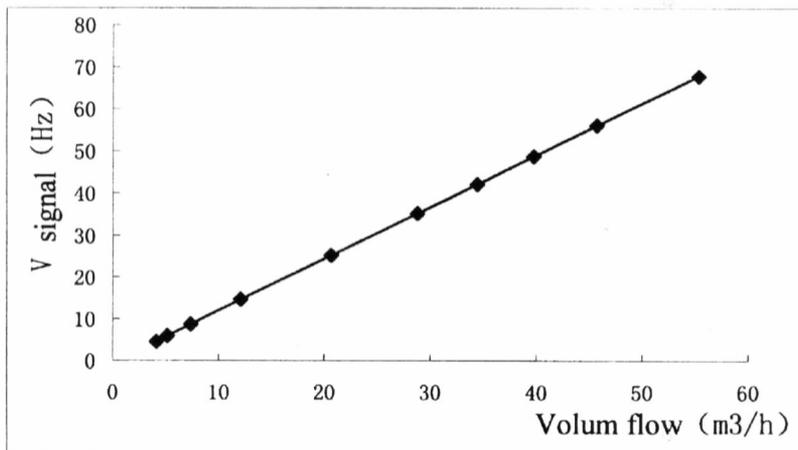


Fig.1 The relationship between volume signal and volume flow

Volume flow property curve is showed in Fig. 2.

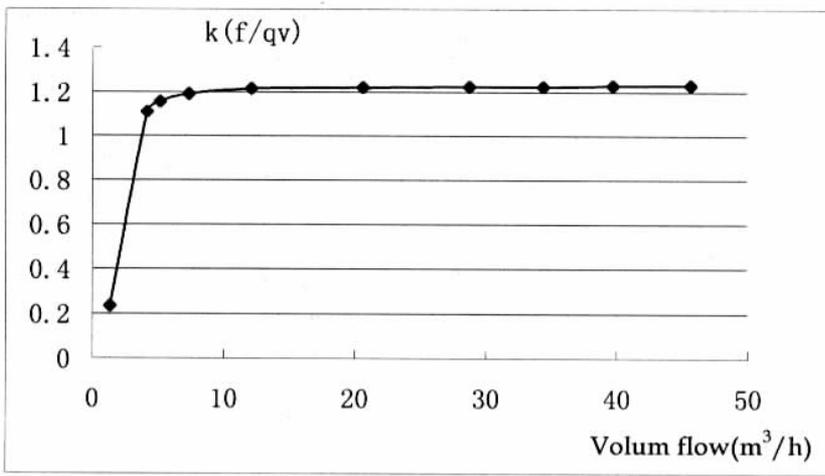


Fig. 2. The volume flow property curve

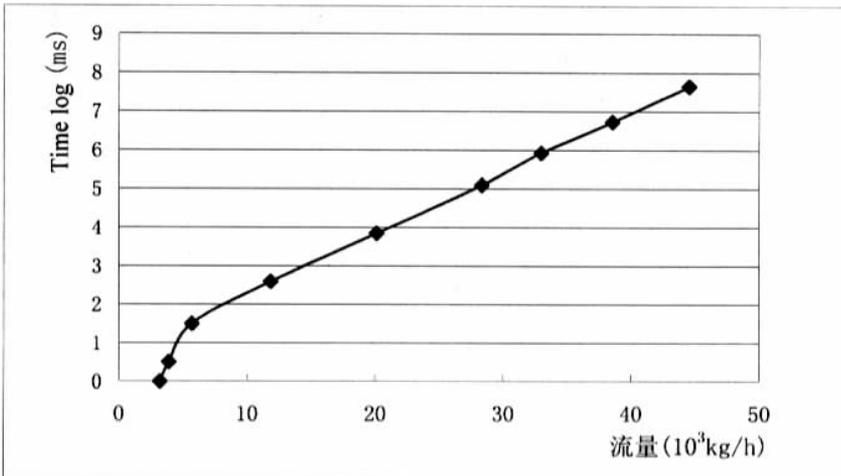


Fig. 3 The correlation between mass flow signal and phasic time lag

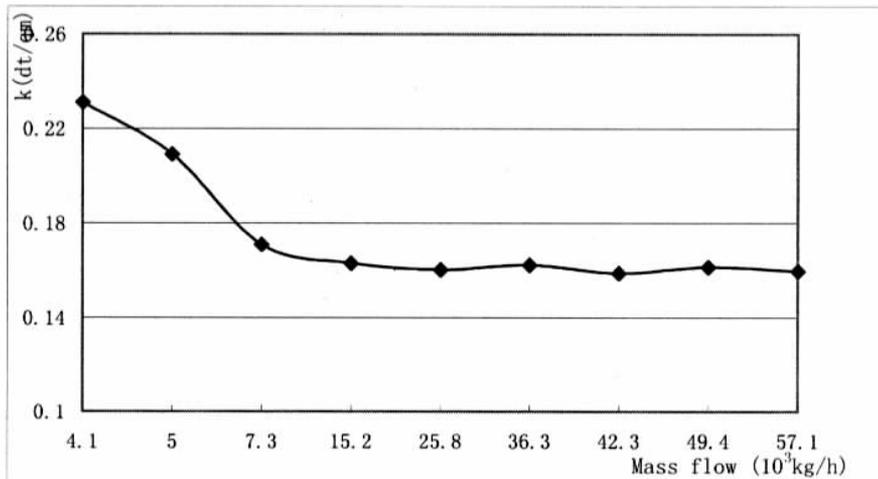


Fig. 4 The property curve of mass flow flowmeter

It is showed from Fig. 3 that the output signal from double turbine mass flowmeter Δt is in linear relationship with mass flow within the certain ranges of flow.

Within the whole range of flow, flow coefficient is not a constant number. When it is within the lower flow ($4.2\text{--}7.3 \times 10^3 \text{ kg/h}$), the flow coefficient will vary with the change of flow. The repeatability error is relatively bigger. When it is within the higher flow (above $7.3 \times 10^3 \text{ kg/h}$),

the coefficient is close to a fixed number. The repeated error is relatively smaller. When it is within the extreme low flow(smaller than $4.2 \times 10^3 \text{kg/h}$), the flow coefficient is extremely unstable. The flow coefficient K can be calculated based on various ranges of flowing rates.

3. The uncertainty analysis for sample flowmeter

Based on four experimental results in table 3 at below, the repeatability error is calculated at Each flowing rate^{<3>}.

$$\text{Repeatability error: } s(E_i) = \sqrt{\frac{1}{m-1} \sum_1^m (E_{i,j} - \bar{E}_i)^2} \quad (3)$$

The average standard difference at each flow rate:

$$s(\bar{E}_i) = \frac{1}{\sqrt{m}} s(E_i) \quad (m=4) \quad (4)$$

Table 1 Repeatability error

Flow (10^3kg/h)	$E_i/\%$	$s(\bar{E}_i)/\%$
4.10	0.1	0.14
5.0	0.34	0.21
7.35	0.08	0.20
15.20	0.04	0.18
25.84	0.04	0.18
36.39	0.08	0.10
42.31	0.07	0.19
49.46	0.07	0.06
57.11	0.11	0.07

The uncertain sources of Signal Δt are from flow standard equipment, temperature, pressure, density, electronical counter, repeatability and etc. Details are listed in Fig. 2.

Table -2 The uncertain sources of Signal Δt

Series	Uncertain Resources /%	Uncertainty inputs	Possible distribution	Covering factor	Standard Uncertainty $u_r(x_i)/\%$	Sensitivity coefficient
1	Standard installation	0.01	Normal	2	0.05	1
2	Liquid density	0.03	even	$\sqrt{3}$	0.0173	1
3	Temperature	0.04	even	$\sqrt{3}$	0.023	1
4	Pressure	0.002	even	$\sqrt{3}$	0.0012	1
5	Electronical counter	0.03	even	$\sqrt{3}$	0.0017	1

(1) The uncertainty of flow standard equipment is 0.05%, covering factor k is 2.

(2) The uncertainty of liquid density measurement is 0.03%.

(3) With every difference of one centigrade, the uncertainty of liquid temperature correction is 0.0002. During the test, the temperature change is less 2 degree of centigrade.

(4) With the change of 0.1MPa, the uncertainty of liquid pressure correction is

0.00005. During the test, the pressure change is less than 0.4MPa.

(5) The uncertainty due to electronic counters includes both the inaccuracy of signals and its inaccuracy of counting. When the frequency of crystal vibration is 12.0MHz, the uncertainty is 0.03% .

The following is the calculation method for A standard uncertainty.

Based on the formula 4, the error of A standard uncertainty is calculated. The maximum Repeatability error number should be used at each flowing rate. $E_r=0.21\%$.

Synthesized standard uncertainty:

$$u_{cr}^2(y) = \sum_{i=1}^N u_{ri}^2(y) = \sum_{i=1}^N c_{ri}^2 u_r^2(x_i) \quad (5)$$

$$\begin{aligned} \text{i. e. } u_{rc} &= \sqrt{\sum_{i=1}^N [|c_{ri}(x_i)| \cdot u_r(x_i)]^2} \\ &= \sqrt{0.05^2 + 0.0173^2 + 0.023^2 + 0.0012^2 + 0.0017^2 + 0.21^2} = 0.22\% \end{aligned}$$

Extended uncertainty U is acquired by synthesized standard uncertainty multiplying inclusive factors k , i.e.

$$U = k u_c(y) = 0.44\%$$

In general, for flow measuring, K $k = 2$. Confidence probability is close to 95%.

Conclusion

On the basis of experimental study of liquid velocity distribution correction of double turbine mass flowmeter, it demonstrates that the sample flowmeter, with the range of $7.35 \times 10^3 \text{kg} / \text{h} \sim 57 \times 10^3 \text{kg} / \text{h}$, relative error range of 0.1%, uncertainty as 0.44%. meet the uncertainty standard ($\pm 0.2\% \sim \pm 0.5\%$) of Class three liquid flow standardized installment.

Reference

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