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Analysis of the Influence of Steam Supply Parameters on ISA1932 Nozzle Flow Measurement Error

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Abstract: At present, inaccurate flow measurement often exists in steam flow meter of steam supply network under variable operating conditions. Therefore, this article takes isa 1932 nozzle flowmeter as the research object, establishes its measurement error mathematical model, studies the influences of steam supply parameters on its flow measurement error under variable operating conditions, and analyses the reasons for these influences. the results show that in the area of small flow (less than 0.3kg/s), the steam supply flow has a great influence on the flow measurement, the flow measurement error of isa 1932 nozzle flowmeter increases by 0.66% for every 0.1 kg/s reduction of steam supply flow. While in the area of large flow (greater than 10kg/s), the steam supply flow has little influence on the flow measurement, and the flow measurement error of isa 1932 nozzle flowmeter approaches zero. Compared with the steam supply flow, the steam supply pressure and temperature have a greater impact on the isa 1932 nozzle flowmeter. In the area where the steam supply pressure is small (less than 0.8mpa), the flow measurement error of isa nozzle decreases by about 0.02% for every 0.1mpa increase in the steam supply pressure. Under design conditions, the flow measurement error of isa nozzles increases by about 0.03% for every 10 °C increase in steam supply temperature.

1. Introduction

Almost every progress of human science and technology is accompanied by an over-exploration of natural resources. The fact that energy is exhausted and global warming is threatening the future of human beings. Due to the relative shortage of energy in China, while the economy is developing rapidly, energy security should also be considered. Fully improving the energy utilization rate can effectively slow down the rate of energy exhaustion. Therefore, the efficient use of energy has always been a major issue parallel to environmental protection [1].

Among them, regional heating is one of the important methods to realize the sustainability of modern urban environment and improve energy efficiency [2]. Regional heating technology has been widely used in Europe, North America and Japan in the past few decades. For example, from 2000 to

2010, the number of cities and towns with regional heating networks in Italy increased from 27 to 104, and the number of kilometers of pipelines increased from 1000 km to about 3000 km. Other European countries have similar growth trends [3].

With the rapid development of industrialization and urbanization in China, the demand for steam in industrial production is increasing continuously. At the same time, with the improvement of people's living standard, the heating area of residents is increasing continuously, the heating area is gradually expanding to the south, and the total heating energy consumption is increasing rapidly. Under the environment of national initiative and implementation of cogeneration of heat and power, central heating and environmental protection, central heating develops rapidly [4].

The steam supply pipe network with steam as heat medium can provide higher heating parameters and meet the needs of various heat users. It has been applied in some industrial zones [5]. Accurate measurement of steam flow in heating pipe network is crucial to maintain the legal rights and interests of both heat users and heating enterprises [6, 7]. Differential pressure steam flowmeter has a wide range and large quantity at present. The ISA 1932 nozzle flowmeter (hereinafter referred to as ISA nozzle) which often used for measuring steam flow is a differential pressure flowmeter [8-11].

The main factors affecting the measurement accuracy of differential pressure flowmeter are steam supply flow, steam supply pressure and steam supply temperature [12-14]. Due to environmental temperature, intermittent steam consumption and other reasons, the steam parameters of the pipe network fluctuate and change drastically, resulting in large error in the measurement results of the flowmeter and confusion in the calculation of the user's steam consumption [15]. Therefore, it is of great significance to analyze the factors that affect the measurement accuracy of steam flowmeter and improve the measurement accuracy of steam flow.

At present, some scholars have studied and discussed the flow inspection and detection method of ISA nozzle [16]. However, little research has been done on the influence of measured fluid parameters on flow measurement of ISA nozzle. Therefore, this paper takes ISA nozzle as the research object, through establishing its measurement error mathematical model, studies the influence rule of steam supply parameters on flow measurement error of ISA nozzle, and analyses the influence of steam supply pressure, temperature and flow on flow measurement of ISA nozzle under variable operating conditions, which provides basis for correcting the results of flow measurement of ISA nozzle.

2. Mathematical Model of Flow Measurement Error of the ISA Nozzle

The nozzle flowmeter measures the steam flow by measuring the differential pressure between the upstream and throat sections where the steam flows through the throttling element [17, 18]. Taking the steam mass flow measured by ISA nozzle as an example, according to the national standard GB/T 2624.1-2006, the steam mass flow q_{m} can be expressed as [19, 20]:

$$q_{\mathrm{m}}=\frac{\pi}{4}d^{2}\varepsilon\frac{C}{\sqrt{1-\beta^{4}}}\sqrt{2\Delta p\rho} \tag{1}$$

$$K=\frac{\sqrt{2}\pi}{4}d^{2}\varepsilon\frac{C}{\sqrt{1-\beta^{4}}} \tag{2}$$

$$q_{\mathrm{m}}=K\sqrt{\Delta P\rho} \tag{3}$$

Where q_{m} is the steam mass flow, kg/s; ρ is the steam density, kg/m^3; C is the discharge coefficient; ΔP is the differential pressure before and after the flowmeter, Pa; ε is the expansion coefficient; β is the aperture ratio, β=d/D, d is the orifice diameter of the throttling element, D is the inner diameter of the pipe, mm; K is the ISA nozzle instrument coefficient, m^2.

The current ISA nozzles produced by manufacturers generally have the density compensation function, as the result the influence of the steam density on the flow measurement error of ISA nozzles is negligible. Therefore, the instrument coefficient K is the main parameter affecting the flow measurement of ISA nozzles. Under reality condition, when the steam supply parameters deviate from the design condition, the flow measurement error of ISA nozzle due to the change of instrument coefficient can be expressed by formula (4):

$$\delta = \frac{q_m' - q_m}{q_m} = \frac{K'\sqrt{\Delta p} - K\sqrt{\Delta p}}{K\sqrt{\Delta p}} \times 100\% \tag{4}$$

Where δ is the flow measurement error of ISA nozzle, %; q_m' is the steam supply flow under variable conditions; q_m is the steam supply flow under the design condition; K is the instrument coefficient under the design condition; K' is the instrument coefficient under variable conditions.

The discharge coefficient and expansion coefficient can be expressed by formula (5) and formula (7):

$$C = 0.99 - 0.2262\beta^{4.1} - (0.00175\beta^2 - 0.0033\beta^{4.15})(\frac{10^6}{Re_\mathrm{D}})^{1.15} \tag{5}$$

$$Re_D = \frac{4q_\mathrm{m}}{\pi D\mu} \tag{6}$$

$$\alpha = \frac{C}{\sqrt{1-\beta^4}} \tag{7}$$

$$\varepsilon = \left[\left(\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right)\left(\frac{1-\tau^{\frac{\kappa-1}{\kappa}}}{1-\tau}\right)\right] \tag{8}$$

$$K = \frac{\sqrt{2}\pi}{4} d^2 \varepsilon\alpha \tag{9}$$

Where α is the flow coefficient; κ is the isentropic exponent; τ is the pressure ratio, $\tau = p_2 / p_1$, p_1 is the upstream pressure of the throttling element, and p_2 is the downstream pressure of the throttling element.

The inner diameter D of the pipe and the orifice diameter d of the throttling element can be expressed by formula (10) and formula (11):

$$D = D_{20}[1 + \lambda_\mathrm{D}(t-20)] \tag{10}$$

$$d = d_{20}[1 + \lambda_\mathrm{d}(t-20)] \tag{11}$$

Where D and D_{20} are the inner diameters of pipes at working temperature and 20℃ respectively, mm; d and d_{20} are the orifice diameter of throttling element at working temperature and 20℃ respectively, mm; λ_D is the average linear expansion coefficient of the steam supply pipe material within the range of 20℃~t; λ_d is the average linear expansion coefficient of ISA nozzle within the range of 20°C~t; t is the working temperature °C.

3. Case Analysis

Taking a heating company in Hebei as an example, three typical thermal users are selected from the company, of which user 1 is closest to the power plant and user 3 is farthest from the power plant.

The influence of steam supply parameters of three thermal users on flow measurement of ISA nozzles under variable operating conditions is analyzed. Steam supply parameters under different operating conditions are shown in Table 1 and design operating parameters of each ISA nozzle are shown in Table 2.

Table 1: Steam supply parameters of thermal users under different working conditions

project		Steam supply flow	Steam supply pressure	Steam supply temperature
unit		kg/s	MPa	°C
Design condition	user 1	4.167	1.782	237.6
	user 2	11.111	1.698	221.9
	user 3	0.556	1.69	218.7
Actual minimum working condition	user 1	0.083	1.53	285.3
	user 2	0.099	1.41	240.3
	user 3	0.097	1.33	220.1
Actual maximum working condition	user 1	1.667	0.752	202.7
	user 2	2.5	0.734	194.3
	user 3	0.278	0.713	180.3

Table 2: Thermal user ISA nozzle design parameters

ISA nozzle	discharge coefficient	aperture ratio	inner diameter	orifice diameter	isentropic exponent	flow coefficient	instrument coefficient	Range
Unit	-	-	mm	mm	-	-	m^2	kg/s
Heat user 1	0.9730	0.5304	259	137.732	1.2962	1.0139	0.0222	1.39~5.56
Heat user2	0.9791	0.4758	460	219.455	1.2965	1.0052	0.0551	9.72~13.89
Heat user3	0.9710	0.5416	100	54.303	1.2971	1.0157	0.0035	0.28~0.83

3.1. Effect of Steam Supply Flow on Measurement Error of ISA nozzle

Figure 1 shows the measurement error curve of ISA nozzle flow with different steam supply flow under the design condition of steam supply pressure and temperature for the heat users.

With the increase of steam supply flow, the flow measurement error of ISA nozzle is gradually reduced and tends to be stable. In the small flow area (less than 0.3 kg/s), the flow measurement error of ISA nozzle increases by 0.66% for every 0.1 kg/s reduction of steam supply flow; In the large flow area (more than 10kg/s), the flow measurement error of ISA nozzle tends to be zero. The main reason is that the small flow area is outside the range of ISA nozzle, and the Reynolds number has a great influence on the outflow coefficient, so the instrument coefficient changes significantly in the small flow area. While the large flow area is also outside the range of ISA nozzle, the outflow coefficient has tended to be stable, so the instrument coefficient tends to approach the instrument coefficient under design conditions.

3.2. Effect of Steam Supply Pressure on Measurement Error of ISA Nozzle

Figure 2 shows the measurement error curve of ISA nozzle flow under different steam supply pressures under the design condition for the steam supply temperature and flow of heat users.

With the increase of steam supply pressure, the ISA nozzle error curve shows a trend of gradual decrease. It is mainly because the expansion coefficient of ISA nozzle increases with the increase of steam supply pressure, while the flow coefficient almost remains unchanged. In the area where the steam supply pressure is small (less than 0.8MPa), the flow measurement error of ISA nozzle decreases by about 0.02% for every 0.1MPa increase in the steam supply pressure.

3.3. Effect of Steam Supply Temperature on Measurement Error of ISA Nozzle

Figure 3 shows the measurement error curve of ISA nozzle flow at different steam supply temperatures for three heat users under the design conditions of steam supply pressure and flow. When the steam supply temperature is higher than the temperature under the design condition, the curve will gradually increase with the increase of the steam supply temperature.

When the steam supply temperature is lower than the temperature under the design condition, the curve trend is opposite. It is mainly because the increase of steam supply temperature makes the orifice diameter of ISA nozzle significantly increase, while the expandability coefficient and flow coefficient almost remain unchanged.

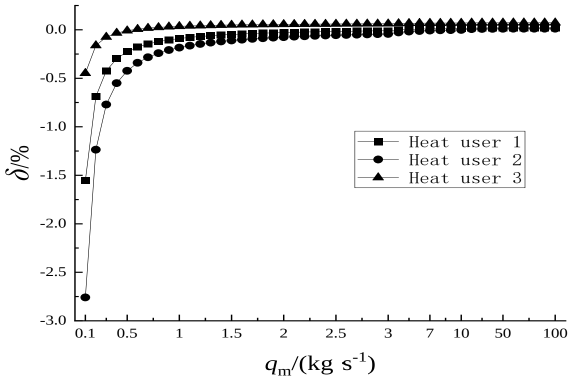

Figure 1: Relative error curve of steam supply flow to ISA nozzle flow measurement of different thermal users

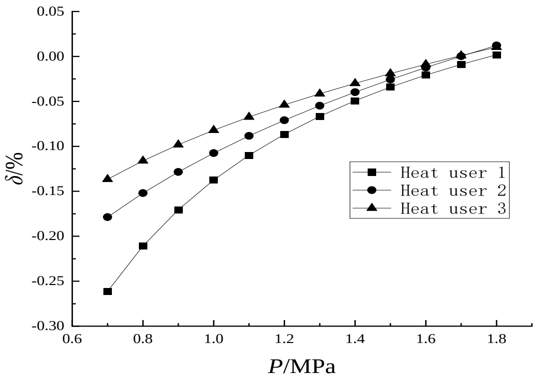

Figure 2: Relative error curve of steam supply pressure versus ISA nozzle flow measurement for different thermal users

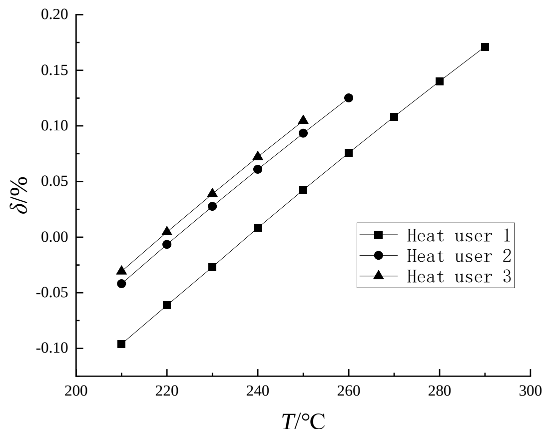

Figure 3: Relative error curve of steam supply temperature versus ISA nozzle flow measurement for different thermal users

Under design conditions, the flow measurement error of ISA nozzles increases by about 0.03% for every 10 ℃ increase in steam supply temperature. It can also be seen from Figure 3 that the trend of flow measurement error curves of ISA nozzles of three heat users is basically consistent. Under design conditions, the flow measurement error of ISA nozzles increases by about 0.03% for every 10 ℃ increase in steam supply temperature.

4. Conclusions

(1) Under the design condition, the decrease of steam supply flow, temperature and pressure will increase the flow measurement error of ISA nozzle. In the small flow area, the steam supply flow has a greater impact on ISA nozzle flow measurement. The smaller the steam supply flow, the greater the ISA nozzle flow measurement error.

(2) Compared with the steam supply flow, the influence of steam supply temperature and pressure on ISA nozzle flow measurement is greater. Under the design condition, the higher the steam supply temperature and the lower the steam supply pressure, the greater the flow measurement error of ISA nozzle.

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