Numerical simulation-based experimental study on the effect of different disturbed flow components on ultrasonic flowmeter metering performance

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Abstract

Ultrasonic flowmeter is a velocity flowmeter, and its measurement accuracy is greatly affected by the flow field in the pipeline. In the actual use process, due to the installation conditions are not ideal, the formation of vortex flow, pulsating flow, asymmetric flow and other non-ideal flow field in the pipe, which in turn affects the accuracy of ultrasonic flowmeter. This study is based on CFD numerical simulation technology, 90° elbow, reducer, upstream and downstream flange diameter difference of one level and other typical disturbance elements on the impact of the flow field in the pipe, simulate the flow field of the gas in the closed pipe after the disturbance elements, and calculate the resulting error, found that the impact of each disturbance element on the ultrasonic flowmeter measurement error increases with the increase in operating flow. For 90° elbow, the upstream and downstream flange diameter differ by one level,we use these two installation conditions to carry out real flow test, through the test data and simulation results for comparison and analysis, the results are consistent. At the same time, the use of experimental data on the simulation model correction, can guide the construction and transformation of ultrasonic flowmeter metering process, improve the accuracy of the measurement results, and effectively maintain the fairness of the trade handover.
Keywords: flowmeter; accuracy; disturbance elements; flow field; numerical simulation; real flow test

1. Introduction

Compared with the traditional flowmeter, ultrasonic flowmeter is widely used in recent years in the field of natural gas industrial production because of its wide measurement range, simple operation, easy installation and the advantages of non-contact flow measurement and high repeatability, It is one of the main instruments for natural gas trade metering work[1-3]. From the principle of ultrasonic flowmeter ,we can easily see that in deriving the calculation model of ultrasonic flowmeter, the measured flow field is assumed to be a fully developed uniform steady flow state, so the non-ideal distribution of the fluid flow field in the pipe becomes one of the important factors affecting the measurement performance of ultrasonic flowmeter[4]. In the actual field station, metering pipe section often exists in all kinds of bends, manifolds, valve bodies and other flow blocking elements, resulting in the flow of fluid into the flowmeter is non-ideal flow state[5], does not meet the ideal flow state assumed by the measurement model, which in turn affects the flow measurement accuracy, so this paper based on the metering pipe section based on the installation structure, the use of CFD numerical simulation technology, by carrying out 90° elbow, reducer, upstream and downstream flange Diameter difference between the first class and other typical disturbance elements on the impact of the flow field in the pipe numerical simulation analysis study, to obtain the gas flow field distribution in the closed pipe and ultrasonic flowmeter section at the velocity distribution of the flow field, through the integral calculation based on the flow field analysis of the measurement error. In addition, in the metering station, carry out 90° elbow, upstream and downstream flange diameter difference of one level of two installation conditions to carry out real flow test, through the test data and simulation results for analysis and verification.

2. Research Method

In this paper, CFD flow field numerical simulation method is used for the study. It is a complete system for studying fluid flow problems together with traditional theoretical analysis methods and experimental measurement methods[6], CFD can be seen as a complete numerical simulation of fluid flow under the control of the basic equations of flow consisting of the conservation of mass equation, conservation of momentum equation and conservation of energy equation. The controlling differential equation of the finite volume method can be represented by a generic transport equation, invoking a generic variable, and the generic variable equation is：

$$\frac{\partial(\rho\varphi)}{\partial t}+\mathrm{div}(\rho\varphi u)=\mathrm{div}(\Gamma\cdot\mathrm{grad}\varphi)+S_{\varphi} \qquad (1)$$

The technical lines of research are as follows.

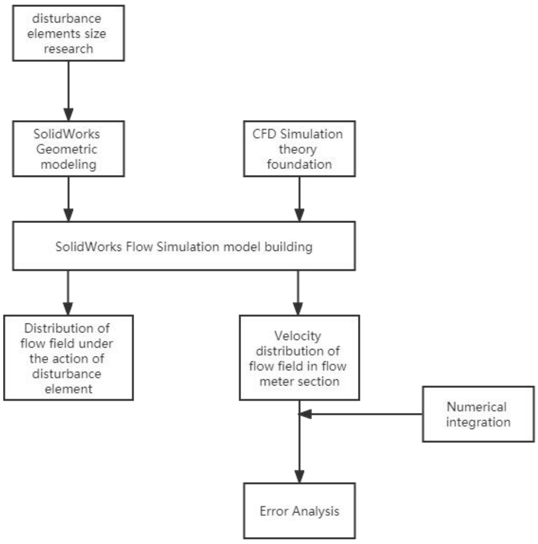


Figure 1： Research technology line.

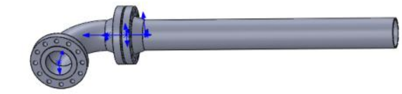
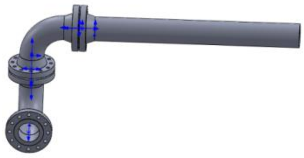
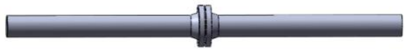
3. Model building and data analysis

In this chapter, CFD software is used to establish the physical model and define the calculated fluid area, and select the suitable turbulence model, wall function, boundary conditions, etc., in order to seek a more realistic simulation effect in the field.

3.1Model establishment

Through the ultrasonic flowmeter field use research, the installation conditions exist in the typical flow blocking parts of the statistics, selected 90° elbow, heterogeneous double elbow, reducer, upstream and downstream flange diameter difference of one level, rectification plate blocking and other disturbing parts of the flowmeter measurement impact on the situation to study. In accordance with the actual installation conditions of the site flowmeter, the pipe, rectifier plate and spoiler elements for assembly, in order to prevent the influence of vortex phenomenon on the results, the length of the straight pipe section downstream of the spoiler 30D, the flowmeter position set at 10D, the establishment of natural gas flow field simulation geometric model, the final geometric model is shown in Table 1.

Table 1: Simulation geometry model of DN200 pipe diameter with different disturbance elements.

Disturbance elemnet	Geometric model
90° Single Elbow	
Profiled double elbow	
DN150 to 200 progressive expansion pipe	
DN250 to 200 tapering pipe	
Difference in diameter between upstream and downstream flanges by one level	
Rectifier blocking	
Throttle shut-off valves with different openings	

3.2 Simulation data solving and analysis validation

The accuracy of numerical simulation simulation is inseparable from various types of condition settings. Taking the DN200 pipe diameter 90° single elbow model as an example, the simulation model calculation process is explained. The initial unit system is set to SI (m-kg-s); the analysis type is selected as internal; the physical characteristics consider the fluid gravity with the value of $g=9.81 m/s^2$; the fluid is set to be a natural gas mixture of 98% methane and 2% ethane; the flow-solid heat transfer is not considered, the wall condition is set to adiabatic wall, and the wall roughness is set to 20 μm; the turbulence model adopts the standard k-ε model, where the turbulence intensity is 2% and the turbulence length is 0.00114 m. The inlet of the calculation domain is set as velocity inlet, and the flow points Q_{min}, Q_t, $0.4Q_{max}$, Q_{max} are converted according to the measured flow rate of the examinational regulation, and the inlet flow velocities are converted to four cases of 0.375 m/s, 8.446 m/s, 16.892 m/s, 42.230 m/s for the study, the outlet is set as The global mesh is divided by finite volume method and SIMPLE algorithm is used for iterative solution.

After the solution is completed, the exact flow value of the measured pipe section downstream of the disturbance is solved by applying the calculus principle based on the pipe flow field distribution, which is calculated as follows:

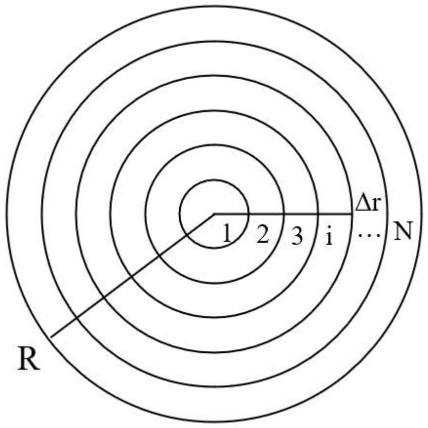


Figure 2: Schematic diagram of pipe flow integration.

The true flow value of the measured pipe section is the area fraction of the instantaneous flow velocity in the pipe over the pipe cross-section A. The pipe is divided into N concentric rings of width Δr. Based on CFD simulation data, the average flow velocity value *v(r)* on each ring is obtained, and when Δr is small enough, the accurate flow value QS can be calculated as follows：

$$Q_S=\iint_A \upsilon(r)dA=\int_0^R 2\pi r\upsilon(r)dr \qquad (2)$$

$$Q_S\approx\sum_{i=0}^{N}\pi\left(r_{i+1}^2-r_i^2\right)\upsilon(r)_i \qquad (3)$$

In formula：

Q_s — flow rate of the pipe based on flow field analysis, m^3/h;

A — circular pipe cross-sectional area, m^2;

R — radius of the pipe, m;

r — radius of the circle, m;

v(*r*) — average flow velocity of the circle with radius *r*, m/s;

r_i — radius of the i-th circular ring, m;

$v(r)_i$ — average flow velocity on the i-th circular ring, m/s;

N — Number of concentric rings divided by the pipe cross section.

With equation 3, the flow value Q_S based on the flow field distribution of the pipe can be obtained, and then the average flow velocity of the cross-section at the pipe can be found. The error at the 10D cross-section downstream of the spoiler is calculated according to Eq. 4, and the results of calculating the error at the 10D cross-section downstream are shown in Fig. 3.

$$E=\frac{Q_S-Q}{Q} \qquad (4)$$

In formula：

Q - pipe flow rate at the model inlet, m^3/h.

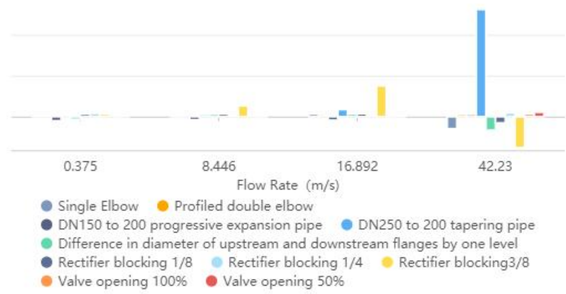


Figure 3: 10D cross-sectional error downstream of DN200 pipe diameter spoiler.

For the 90°elbow, the upstream and downstream flange diameter difference between the two installation conditions to carry out the real flow test. For 90°elbow installation conditions selected 0.375 m/s, 16.892 m/s two flow points, the upstream and downstream flange diameter difference between the installation conditions selected 0.375 m/s, 8.446 m/s, 16.892 m/s three flow points. The error comparison is shown in Figure 4, it can be seen that the software simulation and the real flow test, the flow pattern for the impact of the flowmeter measurement error has consistency.

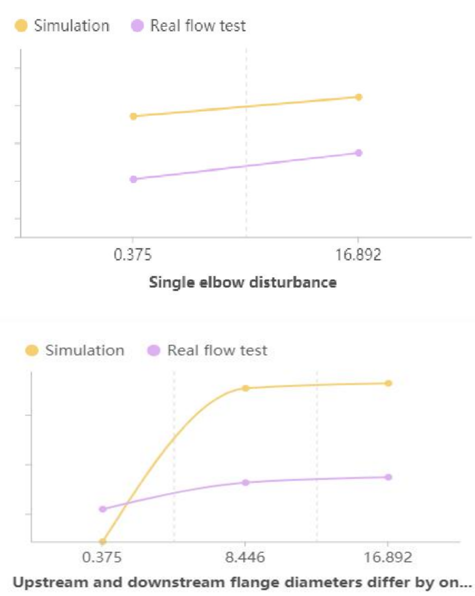


Figure 4: Comparison of simulation simulation and real flow test error for the same disturbed flow.

According to the above calculation results, the error analysis of the average flow velocity and its error at the surface 10D downstream of different disturbances.

3.2.1 through the flowmeter position surface level flow rate calculation and error analysis can be derived under each condition of each disturbance element caused by the downstream 10D surface average flow rate and the flow rate error within the measurement range of the flowmeter. DN200 pipe diameter of different types of disturbance element downstream 10D average flow rate error range as shown in Table 2.

Table 2: Error range of the average flow velocity at 10D downstream of the disturbance elements.

Disturbance elements	**Single Elbow**	**Profiled double elbow**	**DN150 to 200 progressive expansion pipe**	**DN250 to 200 tapering pipe**	**Upstream and downstream flange diameter difference of one level**
Error Range	0.22%~ 14.64%	1.41%~ 2.76%	0.5%~1 30.82%	2.69%~ 4.93%	3.07%~ 16.45%
Disturbance elements	Rectifier blocking 1/8	Rectifier blocking 1/4	Rectifier blocking 3/8	Valve opening 100%	Valve opening 50%
Error Range	3.20%~ 7.54%	1.62%~ 4.60%	3.22%~ 37.84%	0.50%~ 5.49%	0.26%~ 3.42%

3.2.2 Different disturbance elements on the downstream straight pipe section of the fluid flow field distribution impact is different: in the flowmeter position velocity distribution are fully developed turbulent state; DN150 to 200 gradually expand the tube on the downstream pipeline flow field distribution has the greatest impact, in the flowmeter position velocity distribution is the most serious non-uniformity.

3.2.3 In the flow rate $Q = Q_{max}$, DN250 to 200 tapering tube, rectifier blocking 3/8 and other disturbing elements by the simulation of the closed flow field field created by the role of the straight pipe section will produce vortex reflux phenomenon, resulting in the flowmeter cross-sectional velocity distribution of serious non-uniformity, affecting the accuracy of the simulation.

4. Conclusion

In this paper, using CFD numerical simulation method, for the ultrasonic flowmeter upstream of the existence of different typical flow blockers, the establishment of natural gas flow field simulation geometry model, study the impact of different disturbing elements on the accuracy of the flowmeter measurement, and combined with the real flow test data, the validity of CFD numerical simulation to supplement verification, the main conclusions are as follows:

4.1 Comparison of the same disturbance element flowmeter measurement results at different flow points, the measurement error increases with the flow rate increase, it can be seen in the flowmeter calibration of the measurement accuracy of large flow points by the disturbance element more obvious impact.

4.2 Through the simulation of different disturbance elements, found that the flowmeter under test in DN200 heterogeneous double elbow on the downstream straight pipe flow field distribution of the smallest impact, in DN150 to 200 gradually expanding pipe disturbance elements on the downstream pipe flow field distribution of the largest impact, according to this situation can be amended as appropriate flowmeter actual installation and calibration conditions.

In the simulation of the working state of the flowmeter, from the perspective of model optimization, the user-defined function (UDF) should be used to reduce the closed flow field domain distortion, and further consider the impact of heat transfer, impurities in the pipe and other factors, the model is corrected to arrive at a conclusion closer to the actual verification, which is also the direction of future research on flowmeter verification intelligence.

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