Study on the Tests of Large-bore Flow Measurement Using FJPE-type Gauging Pipes

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Abstract: Several tests using FJPE-type gauging pipes for improving the accuracy of large-bore flow measurement have been described herein. The measuring test of non-fully developed pipe flow, which is formed in the elbow, is discussed especially, including research processes, part of data-processing result, and flow velocity profiles at the cross-section of pipes. The initial results indicate that, measurement of large-bore flow by varied-bore pipe is of significant flow-rectifying effects, which reduces the length-requirements of straight tubes as well. The gauge constant fluctuated little within the larger Reynolds number range. This kind of research provides a new method for large-bore flow measurement.

Keywords: Metrology, Large-bore flow, FJPE-type pipe, Varied-bore Pipe, Non-fully developed pipe flow

1.INTRODUCTION OF THE TEST STUDY

Plug-in type flow meter is widely applied for larger-bore flow measurement for the advantages of simple structure, light weight, easy assembly and little pressure drop. Plug-in type flow meter is divided into two kinds: point flow velocity type (e.g. Plug-in type turbine flow meter, plug-in type vortex flow meter and plug-in type ultrasonic flow meter) and pipe diameter velocity flow meter (e.g. Anubar). All of the point flow velocity plug-in type flow meters are used to measure the flow velocity of some point on the pipe section and then the pipe flow is calibrated, while the pipe flow is calculated using the latter kind of flow meter based on the integrated flow velocity value of some diameter on the pipe.

Flow is calculated by plug-in type flow meter based on flow velocity measurement. Calculation model is established based on the condition of flow within pipelines being non-fully developed flow. To achieve fully developed flow, instrument installation requires longer straight tube. According to ISO7145[1]international standard, when using only one elbow, and measured probe located at the center of pipeline, the length of the straight tube must be longer than 25D (D being the diameter of pipeline). Under other conditions, the straight tube must be much longer than 25D. However, the actual work field condition can not meet such requirements, resulting in measure error being above 15%.

Under conditions of fully developed pipe flow, FJPE-type gauging pipe flow meter developed based on Pitot pipe method has applied successfully on large-bore gas flow measurement in national Metallurgical Industry. The applications of nearly one thousand gauging pipe flow meters indicate that this kind of flow meter has the functions of anti-clogging and auto-draining. It can be installed, uninstalled and purging with continuous flow and operating reliably. But on the other side, the straight tube lengths are hardly to be qualified on actual work field, especially in Metallurgical Industry. Most of conditions are that the front straight tube length is ≤10D (normal length is 3D to 8D), which affects the measuring accuracy. Therefore, the method study on large-bore flow measurement under actual work field pipeline conditions (non-fully developed pipe flow included) is still an important research in the area of flow measurement technologies. In order to search a method for improving the accuracy of plug-in type flow meter, our company has conducted a great number of tests by EJPE-type gauging pipe flow meter (gauging pipe as follows) focusing on three aspects.

1.1 Interference Coefficients Test

Locate the gauging pipe in the center of pipe line. The upstream baffles of the pipe are two 90°elbows on same plane and the distances between the baffles and the gauging pipe are 6D and 24D. Determine the interference coefficient γ[2] which represents the effect of work field pipeline on measurement. In an actual measurement, set different interference coefficients to revise the measured flow values in compatible with the length of the straight tube. By this, report of Test Study On Interference Coefficient γ By Gauging Pipe At The Center of The Pipeline [3] was accomplished.

1.2 Pipeline Flow Velocity Distribution Test

To further master the distribution regulations under the condition of having shorter straight tube with non-fully developed pipe flow, the measurement will be conducted according to the method for measuring the non-fully developed pipe flow described in ISO7194 [4]. The cross-section is divided into 8 radiuses (4 diameters), and on each radius 5 velocity-measuring points will be set resulting in 41 measuring points together with one point in the center to measure the cross-sectional flow velocity distribution. For this test, the upstream baffle is one 90° elbow and the distances between elbow and measured cross section are 3D and 8D respectively. Process the test data to gain the flow velocities on 4 diameters. Analyze the flow values achieved through 5 gauging pipes plugged in at the same time resulting in the conclusion that the uncertainty for flow measurement can be controlled within 4% when 5 gauging pipes are plugged at the same time and the paper Test Study on Non-fully Developed Pipe Flow by EJPE-type Gauging Pipe [5].

1.3 Varied-bore Gauging Pipe Test

One problem for large-bore flow measurement is the low flow velocity which makes the measured biases being big. Adopting the varied-bore pipe can effectively accelerate the flow velocity. Gauging pipe, integrated with the EJPE-type gauging pipe is called varied-bore gauging pipe flow meter. Varied-bore gauging pipe flow meter is composed of varied-bore pipe, throat, diverging pipe and gauging pipe. Varied-bore pipe is an axisymmetric body with the arc radius being R. The throat is a pipe with diameter being d. Diverging pipe is a truncated cone with the vertex angle beingα. Gauging pipe is inserted through the throat (Fig.1). After flow passing the varied-bore pipe, flow velocity will be accelerated.

The average flow velocity at throat will be as follows:

$$V_2 = \left(\frac{D}{d}\right)^2 V_1 \qquad (1)$$

Where, V_2=throat average flow velocity
D=pipeline diameter
d=throat diameter
V1=average flow velocity of pipeline

Diverging pipe is the pressing build-up pipe which reduces permanent pressure loss. In this paper, test using varied-bore gauging flow meter will be described.

2.DESCRIPTION OF THE TEST

2.1 Testing System

The testing system is shown in Fig.1. The pipe diameters are 512mm and 306mm.

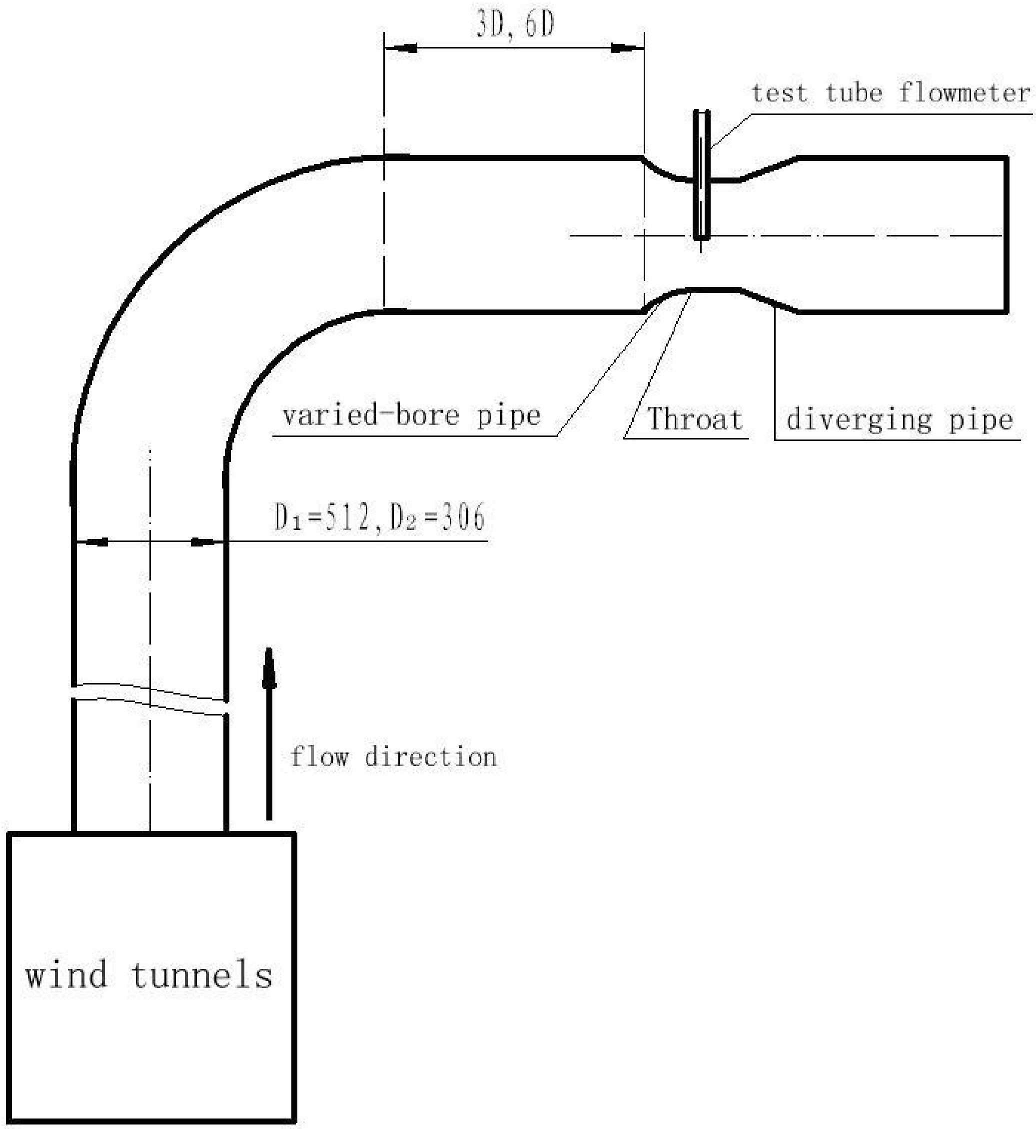

Fig.1 Testing System

2.2 Test Procedures

Gauging pipe will be located vertical to elbow plane and parallel with elbow plane respectively. Put gauging pipe to the center of the pipeline. Flow velocity measurements are at 5 measuring points varying from 3m/s to 30m/s. Adjust the plug-in depth under the same flow velocity for 5 times totally. Sample the differential pressure signal of the gauging pipe output by computer 30 times at each measuring point. The average value will be the differential pressure value of the measurement.

3.TEST DATA&DATA PROCESSING

3.1 Test Data

The test data are omitted herein.

3.2 Data Processing

Limited data processing results are enumerated herein. The pipe diameter is 512mm and throat diameter is 306mm.

Table 1 The straight tube is 20D between elbow and instrument and the gauging pipe is vertical to elbow plane

pipe diameter D1(mm) :306 Humidity(%): 0 Isoentropic index κ :1.4 Insert depth H(mm) :153 Probe constant Kcp: 0.685					
Test status:512-306,20D,insert depth 153				Test time: 09-03-14	
Serial No	1	2	3	4	5
P11(MPa)	0.09982	0.09989	0.10007	0.10037	0.10126
P12(MPa)	0.09982	0.09989	0.10007	0.10037	0.10092
t1(℃)	10.8	10.8	10.8	10.8	10.8
q（m^3/h）	2338.13	4949.8	8104.99	12589.97	18658.93
ΔP(Pa)	100.322	452.271	1299.67	3193.25	6899.44
ReD	189679.0	401830.0	659159.0	1026983	1535542
V（m/s）	8.76444	18.5791	31.3712	48.7663	70.5295
Vcp（m/s）	8.87951	18.7977	30.7802	47.8127	71.0996
K=V/Vcp	0.987	0.988	1.019	1.02	0.992
Kcp	1.0034	1.0034	1.0034	1.0034	1.0034
ΔK	-0.0165	-0.0152	0.0157	0.0164	-0.0115
ΔK/Kcp(%)	-1.64	-1.51	1.56	1.64	-1.15
ρ1(kg/m^3)	1.224756	1.225615	1.227825	1.231508	1.238261

Table 2 The straight tube is 8D between elbow and instrument and the gauging pipe is vertical to elbow plane.

pipe diameter D1(mm) :306 Humidity(%): 0 Isoentropic index κ :1.4 Insert depth H(mm) :153 Probe constant Kcp: 0.685					
Test status:512-306,10D,insert depth 153				Test time: 09-03-14	
Serial No	1	2	3	4	5
P11(MPa)	0.09982	0.09992	0.10009	0.10042	0.10136
P12(MPa)	0.09982	0.09992	0.10009	0.10042	0.10136
t1(℃)	15.5	15.5	15.5	15.5	15.5
q（m^3/h）	2170.24	5438.147	8354.87	12138.57	18511.54
ΔP(Pa)	85.9751	552.142	1338.48	2848.61	6757.87
ReD	171259.0	429569.0	661090.0	963649.0	1483347
V（m/s）	8.18105	20.6874	32.0917	46.4871	70.2706
Vcp（m/s）	8.24103	20.6502	31.7258	46.0936	70.2936
K=V/Vcp	0.992	1.001	1.011	1.008	0.999
Kcp	1.0021	1.0021	1.0021	1.0021	1.0021
ΔK	-0.0094	-0.0004	0.0094	0.0064	-0.0025
ΔK/Kcp(%)	-0.9386	-0.0325	0.9385	0.6395	-0.2449
ρ1(kg/m^3)	1.204753	1.205961	1.208014	1.211999	1.22335

Table 3 The straight tube is 3D between elbow and instrument and the gauging pipe is vertical to elbow plane.

pipe diameter D1(mm) :306 Humidity(%): 0 Isoentropic index κ :1.4 Insert depth H(mm) :153 Probe constant Kcp: 0.685					
Test status:512-306,3D,insert depth 153 Test time: 09-03-14					
Serial No	1	2	3	4	5
P11(MPa)	0.09982	0.0999	0.10008	0.1004	0.10125
P12(MPa)	0.09982	0.0999	0.10008	0.1004	0.10125
t1(℃)	14.8	14.8	14.8	14.8	14.8
q（m^3/h）	2318.87	5092.347	8449.01	12267.7	18464.3
ΔP(Pa)	94.9277	477.869	1309.74	2781.21	6328.66
ReD	183738.0	403821	671210.0	977698.0	1484009
V（m/s）	8.58571	19.2293	31.7115	45.8935	68.0621
Vcp（m/s）	8.80555	19.3374	32.0838	46.5848	70.1153
K=V/Vcp	0.975	0.994	0.988	0.985	0.97
Kcp	0.9825	0.9825	0.9825	0.9825	0.9825
ΔK	-0.0076	0.0118	0.0058	0.0026	-0.0119
ΔK/Kcp(%)	-0.7665	1.2	0.5936	0.2642	-1.21
ρ 1(kg/m^3)	1.207691	1.208659	1.210838	1.214712	1.225002

Table 4 The straight tube is 3D between elbow and instrument and the gauging pipe is parallel with elbow plane.

pipe diameter D1(mm) :306 Humidity(%): 0 Isoentropic index κ :1.4 Insert depth H(mm) :153 Probe constant Kcp: 0.685					
Test status:512-306,3D,insert depth 153,Turn 90 Test time: 09-03-14					
Serial No	1	2	3	4	5
P11(MPa)	0.09982	0.09992	0.10009	0.10042	0.1013
P12(MPa)	0.09982	0.09992	0.10009	0.10042	0.1013
t1(℃)	15	15	15	15	15
q（m^3/h）	1975.75	5309.463	8452.069	12280.8	18446.15
ΔP(Pa)	70.1867	517.299	1338.42	2853.46	6457.83
ReD	156368.0	420630.0	670736.0	977790.0	1481550
V（m/s）	7.38579	20.0091	32.0631	46.4853	68.7283
Vcp（m/s）	7.50260	20.1617	32.0953	46.6342	70.0461
K=V/Vcp	0.984	0.992	0.999	0.996	0.981
Kcp	0.99	0.99	0.99	0.99	0.99
ΔK	-0.0057	0.0023	0.0089	0.0067	-0.0089
ΔK/Kcp(%)	-0.5718	0.2359	0.8994	0.6782	-0.8994
ρ 1(kg/m^3)	1.20685	1.20806	1.210116	1.214108	1.224754

4.TEST RESULTS ANALYSE

1) As shown in Table1 to Table 4, when gauging pipe is located at the center of passing section at the throat, the flow velocity of center is approximately equal with the average velocity at the throat. The instrument's deviation is 1.6% when flow velocity varies from 3m/s to 30m/s, which indicates that the velocity at the center is approximately equal with the average flow velocity and is of little Reynolds number effect. This has resulted in a simple design of instrument calculation software and convenient compensation.

2) When the upstream baffle is an elbow and the front straight tube is 20D, 8D and 3D, the instrument constant desperation will be ±1.05%, indicating that varied-bore gauging pipe flow meter has no sensitive effect on baffles, and can operate normally in shorter straight tubes.

3) The differential pressure value is greatly increased. According to the test data, pressure loss is 20% of the differential pressure.

5. CONCLUSIONS

Lots of experts on flow measures have reached a consensus that the actual work field condition has an inegligible impact on the accuracy of flow measurement result. Obviously, two solutions are available for this problem, one of which is to choose proper measured sites qualified for the requirements of instruments' using or establish a qualified environment through methods like putting on a flow conditioner. Tests by simulation of the actual work field conditions is another solution through which some regularities will be found out and corrections will be made.

In practice, the actual work field conditions cannot meet the requirements of instruments' using. Installation of the flow conditioner can improve it on some extent. However, this method can not be applied directly on all the primary devices. According to GB/T2624-006, flow conditioner must be tested compatibly with specific primary device to allow the application on the same sort of primary device [6]. Uncertainty of flow measurement must be identified through tests.

A series of tests conducted by our company using gauging pipes are to directly revise the flow measuring values based on the second method. They are compatible with the requirements of standards under specific baffle (elbow) conditions. Testing results have been partly applied in the actual measurements. The flow calculator has the function of interference coefficients correcting. Once the straight tube length between elbow and gauging pipe is input, the interference coefficients can be achieved to revise the flow measurement value. For example, the straight tube length on the DN1400 gas pipeline of Panzhihua Iron and Steel Co., is 4D. Flow measurement values were revised based on the flow velocity distribution tests which had gained excellent results and user's satisfaction.

However, the revise is not so perfect for the lack of test data. But it should be believable that simulation of the actual work field is among the efficient solutions for the problem that the actual work field affects on flow measurement. With the accumulation of test data, this revise method will be improved.

REFERENCE

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