Research on Insert Double Ventrui Tube Measuring Equipment

Liu Jianhua[1] , Chen Guanghui[2]
(1. Xian Hanglian Measurement & Control Equipment Co. Ltd., Xi'an, 710043)
(2.Xi'an Industry Institute, Xi'an, 710043)

ABSTRACT: The essay herein analyses and compares the mainly existing problems for the measurement of the air flow that is of lower velocity and in large diameter duct. Through the wind tunnel test, the research is emphasized on the characteristics and mathematical model of the insert double ventrui tube and describes the structure, composition, erection, specialties and application of such tube and its advantages when applied in the measurement and control of assistant combustion air, cool air and coal air (blast furnace coal air, cokery coal air and converter coal air) of the heating furnaces in metallurgy as well as that of the first and secondary air of the boilers and other kinds of air flow of lower velocity and in large diameter duct in thermal power plant.

KEY WORDS: Insert double ventrui tube, large diameter, large flow, contaminated air, high measuring accuracy

1. Introduction

In the production of the present trades of power, metallurgy, petroleum and chemicals, the first measurement elements are mainly of Anuba uniform flow tube, aerofoil shape measuring device, or even traditional standard ventrui tube or orifice plate for measurement and control of coal gas, natural gas, liquid type organic substances in large diameter duct and of large flow; for that of first and secondary air flow of the boilers, fume in the flue, heat return of generator set, and steam flow of heat return in thermal power plant; for that of commercial settlement of coal gas plant; for that of air supply of blast furnace coal gas, cokery furnace coal gas, hot air, assistant combustion air and cool air of metallurgic plant. However, the uniform flow tube is not quite accurate in measurement and has to be associated with pressure difference transducer in application due to the weak signal of pressure difference output and low resolution. And as for aerofoil device it can hardly be reliable because of its huge size and difficulty for manufacturing and cleaning of the signal tube when obstructed by the contaminated air measured. And the standard ventrui tube and orifice plate are confined of popularization and application as the pressure may be greatly lost.

Specially considering the above mentioned problems, on the basis of the latest developed researches of aerial pneumatic theory and hydrokinetics of airplane engines, we have invented the BYW-F insert double ventrui tube measuring equipment upon the computer technology and analysis of abundant data of wind tunnel test. The insert double ventrui tube has been issued with the new practical patent certificate by the nation and awarded with the Prize for Science & Technical Advancement by relative authorities of Xi'an.

2. Structure and measuring theory

The insert double ventrui tube measuring equipment is a brand new invention highly accurate and intelligent in measuring air flow on the basis of basic theories of hydrokinetics and aerial engine, mainly designed for flow measurement and control of the air flows in ducts of large diameter, with lower pressure, with lower velocity and with medias of mixed composition. The measurement and control are realized through data collection and treatment of various parameters of the media, such like velocity, volume, temperature, pressure and pressure difference etc. The success in the research and fabrication of this product will greatly influence the development of the measuring technology and instrumentation industry in our country, as it not only resolves the problems of obstruction of signal tubes and shortage of straight tube at the erection position suffered long time since by those ordinary measuring devices for the media of low velocity, large diameter, small pressure, mixed composition and contamination, but also has the characteristics of high data collection speed and measuring accuracy. As the new generation of pressure difference flow measuring equipment, it has been technically evaluated to reach the advanced level both in China and the world and has proved its goodness in the application in the industrial

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The patent No. of the insert double ventrui tube mentioned in this essay is 98219014x.

measurement.

2.1 Basic theories

According to the basic theories of Bernoulli's equation and continuity equation in hydrokinetics, the data obtained through wind tunnel test and our years of professional experiences, we have summarized the mathematical calculation model (with full automatic compensation for pressure and temperature) for the insert double ventrui tube as below:

$$Q=\frac{A\cdot(t+273.16)^{1.5}}{t+395.16}+B\cdot\sqrt{\frac{\Delta P(P_H+P_0)(P_H+P_0-\Delta P)}{[C(P_H+P_0)+\Delta P](t+273.15)}} \quad (1)$$

In the above formula, A, B & C refers to constant, which is calculated by the technical parameters of the working status of the measured media and the cross section shape and area of the air duct and is verified by the wind tunnel test. (A refers to the changeable temperature function when $\Delta P \neq 0$)

ΔP – pressure difference obtained by the meter (Pa)

Q – flow volume of the measured media (Nm^3/h)

t – flow temperature of the measured section (℃)

P_0 – local average air pressure (Pa)

Upon the verification by experiences and wind tunnel test, the above formula can further be simplified as:

$$Q = K\sqrt{\frac{\Delta P \cdot P}{T}}$$

In the formula

K – constant, the value obtained through theoretical calculation upon the enterprise standard and verified by the wind tunnel test

Q – value of flow (Nm^3/h)

T – absolute temperature (℃)

P – static pressure (absolute pressure) obtained on the front straight section of the ventrui tube (Pa)

ΔP – pressure difference obtained by the ventrui tube (Pa)

This mathematical model only applies to measurement of air. Whenever the measured media is coal gas, natural gas or of any other kinds, detailed values of composition value and relative humidity shall be listed so as for the conversion of physical parameters between air and gas such as isentropic index, expansibleness factor and compression factor etc. to work out the measured flow, which then enables the measurement and control of the media flow in the duct.

2.2 Key technologies

The key technologies of the insert double ventrui tube include the geometrical structural design and the unique calculating software. The core element is composed of external inductive rectifying unit and first sensing component. The external inductive rectifying unit, as the crucial part of the tube, is the necessary condition for the formation of the large pressure difference ΔP of the first sensing component and determines the grade and value of the system pressure difference. The first sensing component is the direct element that receives the pressure difference signal. The duct can be rectangle duct or round.

The flow status of the air in the flow meter is very important, directly influencing the performance of the measuring equipment. The experiment shows that the novel structural design of this equipment is beneficial to the stability of the interior air flow. The insert double ventrui tube measuring equipment has its minus pressure testing point coming from the throat of the interior duct and the pressure is measured on multiple points at the same cross section at the throat to increase the stability of the signal. Then the signal is transferred by the connection tube to the other control units such as pressure difference flow meter and temperature pressure difference flow meter etc. And through the research done on the front straight tube of the pressure difference flow meter, it is discovered that the minimum dimension of its front can be 0.3 times of the diameter of the smallest duct, which, as a result, will greatly reduce the size of the flow meter and its length is decreased more than 15 times of that of the standard ventrui tube.

To minimize the vortex and turbulence when the air is passing through the pressure difference flow meter, three additional clipper-built aerofoil supports are placed at the inlet of the flow meter, which plays both roles as supporting and rectifying. This method is verified to be very effective through experiences.

The traditional pressure difference flow meter cannot so easily obtain the tiny difference of the low velocity and low pressure air. Even when some minor pressure difference transducers of high accuracy are adopted, the resolution is still too low to collect. Therefore, this product is intended to accurately measure and control the flow, which is realized by the erection of a set of insert double ventrui tube pressure difference flow meter and other pressure, temperature and pressure difference control components to change the sectional air flow field inside the duct, increase the velocity and create larger sectional pressure difference, upon which series of theoretical calculation and wind tunnel tests are performed to find out the function relationship between the pressure difference, temperature, volume, pressure, and composition change.

2.3 Technical characteristics of the insert double ventrui tube

The product is mainly for measurement and control of the various air media in large diameter duct, of large volume, low pressure, low velocity and without straight tube section. The novel techniques are as following:

2.3.1 Unique structural design

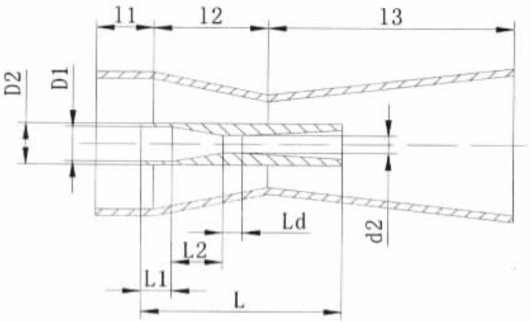

Fig. 1 Sketch of the sensing component structure of the insert double ventrui tube

The pioneer design allows the ratio (β) between the throat diameter (on the pressure difference checking component) and duct interior diameter to be as big as 0.75 that goes much beyond the scope stated in the relevant international standards. The dimension of the checking component varies along the variation of the measured duct diameter and has a very small resistance to the air flow, being only 3%~15% of the kindred products so as to greatly increases the effectiveness and reduce the energy loss. Meantime, the additional dirt exhausting unit is equipped to make the equipment free from the removal and maintenance and ensure the long-term safe running.

2.3.2 High Measuring Accuracy

The high measuring accuracy is apparent:
Velocity measuring tolerance: 0.01m/s;
Volume: Grade 0.5;
Pressure: Grade0.2;
Temperature: Grade 0.2;
Computer software tolerance: less than 1 / 10000.

2.3.3 Wide Range of Measurement & Control

The measuring range ratio of the product can reach 1:10 while that of the ordinary pressure difference flow meter is only from 1:3 ~5. the measurable speed of the media ranges from 4.8m～90m/s while it is difficult for the ordinary pressure difference flow meter to measure the air flow whose velocity is less than 20m/s.

2.3.4 Small Size & Cost Effective

The self length of the product is only 0.3D—1.5D of the pipe diameter while other kindred products require as 10D～24D. Its application will help to save the cost by at least 3 times.

2.3.5 Small Pressure Loss & Power Consumption

The experiment shows that under the same conditions the permanent pressure loss of the product is merely 3～5% of the kindred products, which greatly reduces the energy consumption during the measurement and increases the effectiveness.

2.3.6 Adequately Supported Computer Software

We have developed and designed the whole set of mathematical model to express the function relationship among velocity, pressure, temperature, pressure difference and composition and produced the linearized calculated computer software to promptly display the result. This technology has supplied the technical gap in this field in the country.

3. Experiment Verification

3.1 Experiment Description

The insert double ventrui tube is tested in the NF-3 low velocity wind tunnel in the aerofoil research center of the Northwestern Polytechnical University. See Fig.2 & Fig. 3 for the experimental erection in the wind tunnel of the flow meter. The experimental cross section is 2.5×3.5m, 12m long, with the experimental air velocity as V = 5~90m/s and turbulence rate as 0.08%. The signal is collected by the 8400 electronic scan valve, collecting speed being 50000 points/s and measuring accuracy being 0.05%. The laboratory is the only one with low velocity and is the pivot cascade low velocity wind tunnel laboratory and pivot laboratory of Science & Industry Committee of the National Defense Ministry.

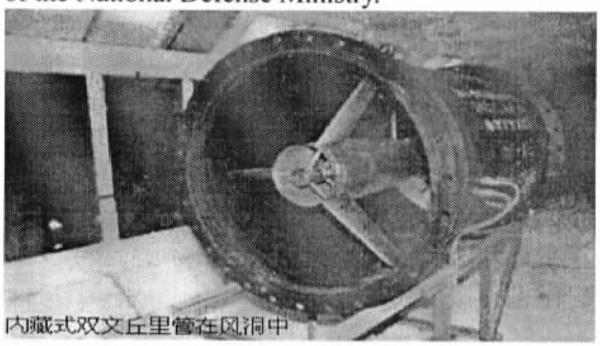

Fig.2 Insert double ventrui tube in the wind tunnel

3.2 Experimental Model

The experimental model is the actual insert double ventrui tube measuring equipment with the outer roundness as Φ1.2m. The outer roundness diameter, i.e. extension duct diameter, is D=1200mm, cross section area being F=1.1304m^2, the throat diameter being d_c=0.045m.

3.3 Experimental Method

During the experiment, the axis of the flow meter coincides with that of the wind tunnel. Prior to the flow meter, erect an extension duct the length of which equals to the inlet diameter of the flow meter. Install 2off static pressure holes on the wall of the extension pipe. The front measuring point P_1 and the middle measuring point P_2 are connected to the U type pipelines respectively with the two reference points of equal pressure in the wind tunnel through hoses. Direct pressure difference readings ΔP_1 and ΔP_2 are accessible from the U type pipelines.

Adjust the air flow velocity in the wind tunnel with the air velocity tube to measure the two static pressure values P_B and P_C of the ventrui tube. Calculate the velocity distribution and flow volume passing through the flow meter with the general pressure value P_{A0} and static pressure value P_A in the extension duct. Test each ventrui tube for twice.

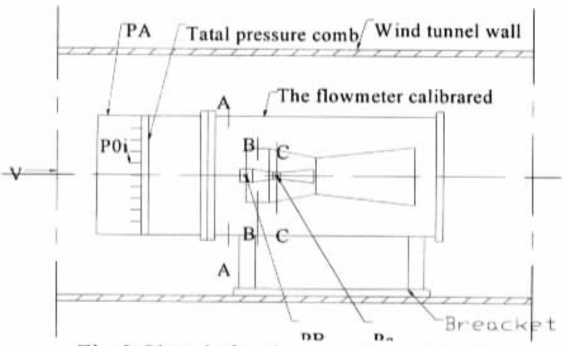

Fig.3 Sketch for the erection of the insert double ventrui tube in the wind tunnel

3.4 Experimental Data & Result

The air is in turbulence status when flowing in the air duct. There is apparently a tolerance when calculating by ideally assuming that the media is unitary to work out the relationship between the pressure difference and the velocity produced by the ventrui tube. Besides, it is very difficult to resolve the flow volume factor in theory during the design of the contraction ratio, as the volume factor is comprehensive and concerned with the type of the throttling unit, pressure taking method, diameter and Re value etc. Consequently, the flow volume factor has to be evaluated under the assistance of the wind tunnel test. After a great deal of experiments, we gradually establish the mathematic model for calculation of flow volume factor K.

The test data is obtained by the following formula:

3.4.1 Flow Volume

$$q_v = V \times F$$

$$q_m = q_v \times \rho_1$$

$$q_m = K_C \times \frac{\pi}{4} \times D^2 \times \sqrt{2 \times \rho_1 \times \Delta P \times 1000}$$

$$\Delta P = P_B - P_C$$

$$\rho_1 = \rho_0 \times \frac{273.15}{273.15 + t} \times \frac{P_1 - P_S \times \varphi_1}{101.325} + \rho_S \times \varphi_1$$

in which

q_v – flow volume (m^3/s)

q_m – mass volume (Kg/s)

V – experimental air velocity (m/s);

K_C – design measurement parameter

D – inlet diameter (m)

ΔP – static pressure difference between ventrui tube inlet and throat (KPa)

P_B – Static pressure of cross section B of double ventrui tube (KPa)

P_C – Static pressure of cross section C of double ventrui tube (KPa)

P_1 – average absolute air pressure (KPa)

ρ_1 – air density under working condition (Kg/m^3)

ρ_0 – air density under standard condition (Kg/m^3)

P_S – vapor pressure in the air (KPa)

φ_1 – relative humidity

ρ_S – vapor content

t – experimental air flow temperature (℃)

3.4.2 *Re* Value

$Re_D = q_m/(0.7854 \times D \times \mu_1)$ （μ_1 – air movement viscousness Pa.S）

Table 1 Experimental Data

V	P_A	P_B	P_C	ΔP
10.0000	-0.0732	-0.0390	-0.9227	0.8837
20.0000	-0.2813	-0.1586	-3.4880	3.3294
30.0000	-0.6135	-0.2911	-7.5595	7.2684
40.0000	-1.1342	-0.4457	-12.6021	12.1564

q_v	q_m	Re_D	Kc
11.3853	12.5309	7.26507×10^5	0.24954
22.7706	25.0618	1.45301×10^6	0.25713
34.1559	37.5927	2.17592×10^6	0.26104
45.5412	50.1236	2.90603×10^6	0.26913

3.4.3 Data Processing

The air velocity V_c (m/s) at cross section C of the duct is

$$V_c = \sqrt{\frac{2}{\rho}(P_C^* - p_c)} \qquad (1)$$

The air velocity V_A (m/s) at cross section A of the double ventrui tube is

$$V_A = \sqrt{\frac{2}{\rho}(P_A - p_A)} \quad (2)$$

The *Re1* passing through the cross section A of the double ventrui tube is

$$\text{Re1} = \frac{V_A d_A}{\upsilon} \quad (3)$$

The *Re2* passing through the cross section C of the duct is

$$\text{Re2} = \frac{V_c d_c}{\upsilon} \quad (4)$$

In which υ - air movement viscousness factor (m^2/s)

The volume Q passing through the duct is

$$Q = V_c S_c \quad (5)$$

In which S_C – cross section of the duct (m^2)

The mass volume passing through the cross section A of the double ventrui tube is (Kg/h)

$$G_1 = 3600 V_A S_A \rho g \quad (6)$$

In which ρ – air density (kg/m^3)

The mass volume passing through the cross section C of the duct is (Kg/h)

$$G_2 = 3600 Q \rho g \quad (7)$$

Resistance factor between C & D cross section is

$$K = (P_c{}^* - P_D{}^*)/Q^2 \quad (8)$$

The static pressure differences between A & B and E & B are respectively

$$P_{AB} = P_A - P_B \quad (9)$$

$$P_{EB} = P_E - P_B \quad (10)$$

3.5 Performance Analysis

As equal section method is used for data processing, the experimental data is repeatable and reliable enough for customer's use. The experimental result indicates that the flow meter is stable, good and complies with the design requirements.

The insert double ventrui tube combines the inside core body with the measuring tube to form a cone shape contraction section between the subulate surface before the inlet and the inner circle of the measuring tube. This cone shape contraction section has a flow adjustment (or rectifying) function similar to or even much better than the classic ventrui tube. The principle of the adjustment function of the cone shape contraction section is: when the media is moving forward in the ventrui tube compartment, as the cross section is gradually decreasing, not only the velocity gets larger and pressure goes lower, but also the media of lower velocity adjacent to the tube wall and the media of high velocity adjacent to the tube axis are mixed together, which gradually reduces the original distribution grads of the high velocity air and corrects the dissymmetrical velocity distribution of deviation or vortex flow formed by the obstruction unit located in the upper stream tube before the compartment so as to ensure the even velocity at the throat of the throttling component as required by the pressure difference flow meter. The adjustment function as described above for the insert double ventrui tube is similar to that of the classic ventrui tube, but with much better effect. This is because the media passing through the classic ventrui tube is pushing from the wall against the axis in the contraction section while the media passing through the insert double ventrui tube is pushing from the axis to the wall in the contraction section to form diffluence. As a result, both the leveling function of velocity distribution grads and the function of correcting the dissymmetrical flow of the insert double ventrui tube are better than those of the classic ventrui tube. Thanks to this effective adjustment function, the insert double ventrui tube is not as sensitive as those traditional orifice plate or nozzle to the change of *Re* value and the throttling diameter ratio β to help maintain good linearity in a wide range of *Re* value (measuring range ratio).

The adjustment function described above also explains why the straight tube section of the insert double ventrui tube can be much lower than that of orifice plate and standard ventrui tube.

There is no sharp edge at the throat of the throttling component of the insert double ventrui tube. The angle between the core column and its front and rear subulate surface is obtuse angle larger than 120°. This structure is very similar to the 'sharp edge passivation treatment techniques on the anti-weariness orifice plate' brought up by the intellectuals of the former Soviet Union for the chamfering of the inlet square angle of the standard orifice plate. The stability of the outflow factor of the anti-weariness orifice plate is already widely acknowledged by instrumentation experts. In fact, in terms of the outflow factor stability, the insert double ventrui tube is better than the anti-weariness orifice plate. The reason is that the anti-wariness orifice plate is only good at resolving the sharp edge weariness but still incapable with the problem of dirt accumulation, both of which two problems are satisfactorily solved by the insert double ventrui tube.

It is also easier to manufacture the insert double ventrui tube than the classic ones. The dimension tolerances of the measuring tube and core body and the relative positions of the two can be strictly controlled, even with larger diameter. Good structure and easiness of manufacturing ensure the high measurement accuracy and also account for the manufacturability by different materials and adaptation to various measuring conditions.

The insert double ventrui tube resolves all the problems that have been suffered by ordinary domestic and foreign made flow measuring equipment caused by air flows in ducts of large diameter, with lower pressure, with lower velocity and with medias of mixed composition, contaminated media, easy obstruction, no straight section or insufficient straight section to disable the signal collection etc. The success in the research and fabrication of this product will greatly influence the development of the measuring technology and instrumentation industry in our country and will improve the situation of our reliance on the importation of key pressure difference flow meters and instruments. It will not only help save the money paid to abroad and export to earn money, but also promote the improvement of the automatization and monitoring abilities in the industries as mentioned at the beginning. It also benefits to the energy saving, effectiveness increasing and quality improvement. It will become more and more important in the monitoring of exhaustion of noxious gas along with the increasing attention on the environmental protection by the government due to its advantages in dealing with the contaminated air so as to create favorable social and economical effects.

4. Conclusion

The extraordinary performance of the insert double ventrui tube will play an important role in resolving the difficulties for measurement of air flow of large volume, low pressure and with high humidity, coal gas and contaminated air etc. The insert double ventrui tube shall be the first choice for those where the traditional pressure difference flow meter has to be continually used and the measuring accuracy and result is expected to be improved. Since the development of the product, it has been successfully applied in the measuring and controlling of high-humidity natural gas, low pressure dirty methane, cokery coal gas, blast furnace coal gas and vapour etc. and the applications are being enriched. It overcomes the measuring defects of the traditional orifice plate and is of simple structure and reliable. As the new generation of pressure difference flow meter, it impregnates new energy in the techniques of pressure difference flow meter measuring and can be widely used.

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Author's resume:

Name: Liu Jianhua

Sex: Male

Place of Birth: Hebei

Technical Title: Senior Engineer (Resercher)

Education: graduated from Beijing Navigation Spaceflight University in 1968

Working experience and awards:

1969—1986 work in 603 Institute of Navigation Ministry

1986—1991 master of Xi'an Hanglian Automatization Reseach Institute

1991 chairman & general manager of Xi'an Hanglian Measurement & Control Equipment Co. Ltd.; standing director of Xi'an Intellectuals Sodality; vice director of Xi'an Private Science & Technology Entrepreneur Association; Expert of Great Contributions awarded by the Xi'an Municipal Government;

The insert double ventrui tube project in which he participated is considered as the national key project for new product development from 2003~2005 by five ministries including Science & Technology Ministry and as the important Production Conversion Project in Science & Technology of 2003~2005 by Xi'an Science & Technology Bureau.

Way of contact:

Floor 13, Dongxing Science & Technology Building, No.1, Xinke Road, Xi'an China 710043

Tel: +86－029－82229229

EMAIL：xahl@xahl.com