The Research and Application of Critical-Flow-Subsonic Venturi Nozzle
(The Extended Application of the ISO 9300 Critical Flow Venturi Nozzle)

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Summary: The ISO 9300 Critical Flow Venturi Nozzle can be operated properly only in critical flow. If critical flow is not obtained, either a wrong measurement results, or the measurement is stopped if U>Ukp is confirmed. In addition, the measuring range of the Venturi nozzle is limited by the working pressure of the air source, therefore, the range of the measurement is small.

Per the ISO 9300 standard, the critical flow Venturi nozzle is transformed into a critical-flow-subsonic Venturi nozzle with function of taking pressure on the throat. A high accurate differential pressure convertor and the corresponding software are introduced, the multi-measuring range intelligent flowmeter with the function of determination of critical pressure ratio is constituted. During the measurement, the flow state is judged automatically. If U≤Ukp, the flow is critical. The calculation of the flow volume and the accuracy of measurement are completely same as the ISO 9300 critical flow Venturi nozzle type. If U>Ukp, the flow is subsonic. The pressure converter engaged in the calculation of flow volume , and a high accuracy of measurement is ensure.

Key words: critical-flow -subsonic critical pressure ratio high-subsonic Function of subcritical flow multi-measuring range

1 Preface

The ISO 9300 Critical Flow Venturi Nozzle can only properly function under thecondition of critical flow. When it is served as the transfer-standard to checkout gas flowmeters, if the air pressure from the source or the indraft air quantity is insufficient, the pressure ratio on the nozzle may not reach the critical value Ukp, which means the flow is not critical flow. In this case, if the symbol of U⩽UKP does not appear, either a wrong measurement occur, or the measurement stopped if U ⩽ UKP is judged. In addition, when the standard flow measurement device by using negative pressure is utilized for the checkup of a flowmeter, a number of critical flow Venturi nozzles are required. This is not convenient to use. when the standard flow measurement device by using positive pressure is utilized for the checkup of a flowmeter, the measurement range is limited by the pressure of the air source and the measurement range ratio is small. A number of critical flow Venturi nozzles are also required and inconvenience the use . This is not convenient to use. As a result, subcritical constant pressure condition is taken as the standard by some manufacturers for the correcton of flowmeters. For sovling the problems in application, it is neccesary to transform the critical flow Venturi nozzle to critical-flow subsonic Venturi nozzle with the function of pressure pickup at the throat. The feasibility of the transformation is discussed theoretically in this paper. The design principles and configuration of the multifunction three-measuring-rang intelligent flowmeter are presented herein.

2 Problems to solve

To design a critical-flow subsonic Venturi nozzle intelligent flowmeter is a new subject. For the following technical issues have to be solved:

2.1 For the design of the sonic section, ISO 9300 standard can be used. For the condition of U =1～0.75, the related specifications of ISO 5167-1 can also be refered to. But for the condition of 0.75＞U＞U_{KP} (critical pressure ratio), there is a gap left, so the key issue is how to extend the measuring range of the critical flow Venturi nozzle. Therefore, a flow measurement equation at high-subsonic condition should be found.

2.2 In order to make study on this subject, a great number of experiments should be conducted. A test model of the critical flow subsonic Venturi nozzle should be designed and manufactured. How to make the product best meet the requirement of use is another key issue.

2.3 Design of the corresponding software is an important part of research work for the critical-flow-subsonic Venturi nozzle intelligent flowmeter .

3 Approaches and measures

The principle of measurement and basic formula at critical flow conditions, and the design and geometric measurements of critical flow Venturi nozzle are complied with ISO 9300. The principles, basic formula, and methods of measurements at low speed flow conditions are based on ISO 5167-1 pertinent standards. At the condition of 0.75＞U＞U_{KP}, how is the formula for the measurement of the flow volume established? After many calculations, it is found that the boundary constraints have to be utilized for obtaining a function of basic subcritical flow, then the substitution of the function into the conventinal flow volume formula yields a formula for high subsonic flow volume calculation. The validity of formula should be proved by experiment data.

For the validation of this formula, a high accurate critical flow subsonic Venturi nozzle is neccesary. Two proposals has been considered. The first one is designed by adding more pressure pickup orifices and a annular chamber on the throat, and the interior geometry remains unchanged. The second is designed by spliting the zozzle at the location on which the throat and the diffuser converge. The diameter at the jointed section is increased by 0.15 to 0.2 mm. In addition, a groove of 0. 5mm in width is given, in which 4 static pressure pickup orifices are arranged and connected to the annular chamber. A static pressure pickup nozzle is attached to the annular chamber. The experiments show that the trailing edges of the pressure pickup orifices in the first proposal have effect of retardarce on the high speed flow, which makes the measured static pressur value enlarged. As a result, it is impossible to correctly determine whether the flow on the nozzle becomes critical. Therefore, this proposal has been abandoned. In the second proposal, the pressure pickup orifices have no effect of retardarce on the flow, and the signal of pressure has high-grade fidelity, the measured data have a good agreement with those by using standard meters.

Therefore, the second proposal is chosen, as shown in fig 1.

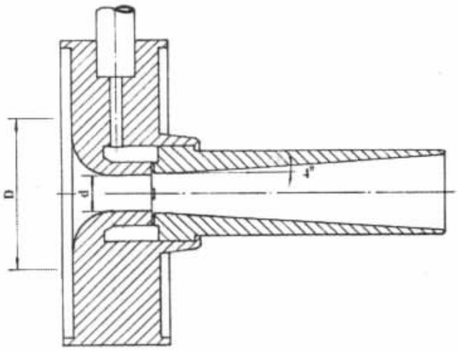

Fig 1 critical-flow subsonic Venturi nozzle

Using the experiment results, make fitted correction to the basic function of the subcritical flow, then an applied formular for the volume calculation of subcritical flow is attained.

The last thing is to design the instrument and software. The proven 12-digit SBC (single board chip) is used on the instrument. The formula for the flow volume calculation is contained in the software, by which the automatic determination of critical flow and switch is implemented.

4 Introduction of the Flowmeter

4.1 Constitution and functions

The Critical-flow Subsonic Multi-measurement Range Intelligent Flowmeter, shown on fig 2,consists of a YYWP critical-flow subsonic Venturi nozzle, a pressure convertor, two differential pressure convertors (a large one and a small one), a small inertial temperature convertor, and a n intelligent flow measurement instrument.

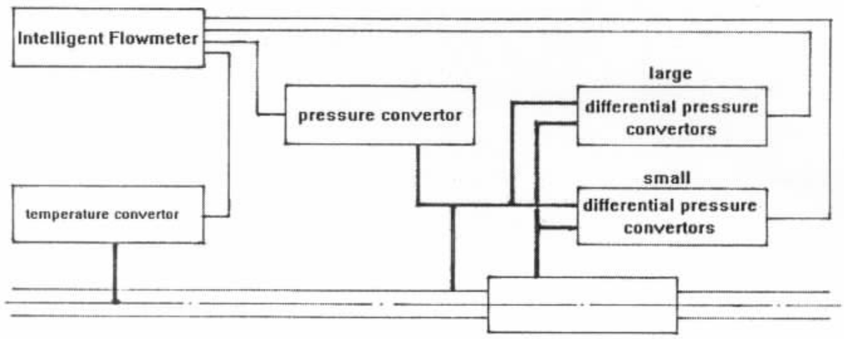

Fig 2 Critical-flow Subsonic Multi-measurement Range Intelligent Flowmeter

It has the functions of three-range measurement. The critical-flow subsonic measurement range is determined and shifted automatically. For any transient flom measurement, the flow condition is determined. If U⩽Ukp, the flow is critical. The accuracy of flow amount calculation and mearuesment is the same as that of the ISO 9300 Critical-flow Venturi Nozzle type. If U>Ukp (0.75>U>UKP or U=1～0.75), the flow is subsonic, then the differential pressure convertor is engaged in the flow amount calculation, and a high accuracy of measurement is obtained.

4.2 Main features

4.2.1 Under the conditions of both critical (subsonic) and subcritical flows, an accurate measurement is gained.

4.2.2 Under the condition of subcritical flow, it has the function of dual-range measurement (a large and a small differential pressure ranges). The total measurement range ratio is great.

4.2.3 It has the function of total compensation for pressure and temperature. In the case of working pressure and emperature variation,the measurement accuracy is ensured.

4.2.4 working pressure and temperature variation, the measurement accuracy is ensured.

4.3 Operating principle

As the gas passes from the front straight part of the conduit through critical-flow subsonic Venturi nozzle, the flow stream is contracted, therefore the velocity of the flow increases and the static pressure decreases. Then a pressure differential ($\Delta P = P_{A1} - P_{A2}$) results between the inlet and the throat md the nozzle. AS the value of U varies from 1 to Ukp, the flow at the throat of the nozzle is accelerated from zero to sonic speed. In the case of $U \leqslant U_{kp}$, a sonic speed flow at the throat of the nozzl remains unchanged.

The characteristics of the flow velocity at the throat of the Critical-flow Subsonic Venturi Nozzle is illustrated in fig 3.

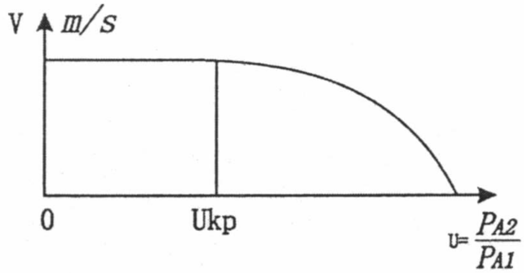

Fig 3 The characteristics of the flow velocity at the thoat of the nozzle

4.4 Flow Volume formula

For critical flow, the mass of the flow passing the Venturi nozzle per hour is calculated by:

$$Qm = K^* \int(p\ .\ t) * \frac{p_{A1}}{\sqrt{T_1}} \quad kg/h \quad (1)$$

For subcritical flow and the operating condition of large pressure differential measurement range, the mass of the flow per hour is:

$$Qm = K_{2y}^* \ Yn2^* \int_y(p\ .\ t) \sqrt{\frac{P_{A1}}{T_1} dP} \quad kg/h \quad (2)$$

For subcritical flow and the operating condition of small pressure differential measurement range, the mass of the flow per hour is:

$$Qm = K_{1y}\ {}^* \int_y(p\ .\ t) \sqrt{\frac{P_{A1}}{T_1} dP} \quad kg/h \quad (3)$$

Where, ∫(p . t) --- function of critical flow

Yn2 --- function of subcritical flow

$\int_y$(p . t) --- function of flow volume

K --- instrument calibrated factor for critical flow

K_{2y} ---instrument calibrated factor for large ΔP measurement range

K_{1y} ---instrument calibrated factor for small ΔP measurement range

ΔP ---pressure differential of the flow between inlet and throat of the nozzle（kPa）

P_{A1} ---static pressure of the flow at the inlet of the nozzle（kPa）

T_1 --- absolute temperature of the flow at at the inlet of the nozzle（t1□+273.15）

4.5 Function of subcritical flow

$Yn2 = \{1 - [1 - Kd1^* C_R/(Kd2^* \varepsilon^* (1000(1-U))^{1/2}]$
$\quad * (0.75-U)^2/(0.75-U_{KP})^2\}$
$\quad * [1 - 1.64^* (U_{KP}-U)^*(0.75-U)]$

Where, Kd1--------38.5423*d^2

C_R ----------k* $[2/(k+1)]^{(k+1)/(k-1)}\}^{0.5}$

Kd2---------6.195797* $d^2/[1-(d/D)^4]$

ε-----------k*$U^{2/k}$*(1-β^4)*(1-$U^{(K-1)/K}$)/ $[(k-1)^*(1-\beta^4{}^*U^{2/k})^*(1-U)]\}^{1/2}$

U------------1-ΔP/ P_{A1}

U_{KP}--------- $(2/(k+1))^{k/(k-1)}$

k------------isentropic index

d------------diameter of the throat (mm)

D----------- diameter of the conduit (mm)

β=d/D

4.6 The characteristics of the flow volume of the Subcritical-flow Subsonic Venturi Nozzle at a given temperature is given on fig 4.

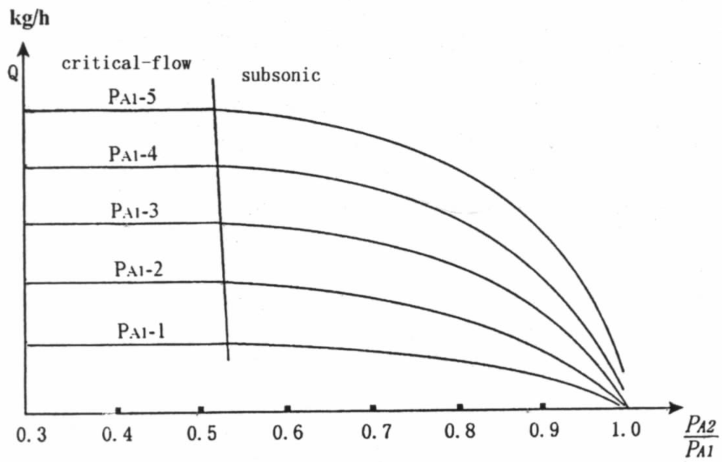

Fig 4 The characteristics of the flow volume of the nozzle at a given temperature

5 Application

Because this product is of multi-measurement range, high accuracy, good repeatability and stability, it has been widely used. It is suitable to the accurate measurement of gases at various working states. It can also be used to substitute for the critical-flow Venturi type nozzle, and to calibrate the ordinary industrial gas measurement instruments,

This product has obtained the manufacturing certificate in the category of measurement instruments awarded by Shaanxi Technical Supervision Bureau. It has been used for the measurement of air, natural gas. AS the standard flowmeter, it is also effectively used for the checkup of actual volume of gas flow. It has complete functions, and is worthy to be further developed and applied extensively.

Reference

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4. JJG640-94 Regulation of the checkup for the pressure differential flowmeter, 1994