ERROR ANALYSIS SYSTEM OF INDUSTRIAL STEAM HEAT FLOW BASED ON NEURAL NETWORK COMPUTER SIMULATION

by

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The paper focuses on the analysis of the neural network mathematical model for temperature and pressure compensation in steam flow measurement, summarizes two types of compensation models suitable for DCS configuration, and introduces the realization of steam flow measurement in ABB Industrial TDCS configuration ways and methods of temperature and pressure compensation. At the same time, the paper uses the scientific neural network intelligent model control method to analyze, optimize, configure and manage the information, improve the operation and management level of the steam system, and realize the optimized operation of the steam system, so as to achieve the purpose of energy saving and consumption reduction.

Key words: *industrial steam, temperature and pressure compensation, heat flow, neural network model, DCS configuration, error analysis*

Introduction

In the petrochemical production process, sometimes the signal directly measured by the transmission unit is used as the controlled variable, which still cannot meet the requirements of process production. For example, the measurement of the flow of steam and natural gas in large-diameter pipe-lines is of great significance to energy saving and cost accounting. In order to improve the measurement accuracy, temperature and pressure corrections are generally required. In the design process of the flow measurement device, the provided design temperature and pressure are different from the actual operating temperature and pressure, or the fluid temperature and pressure fluctuate greatly due to the process conditions, so the measured flow cannot truly reflect its work the actual flow in the state. Most flowmeters can guarantee high measurement accuracy only when the fluid working conditions are consistent with the design conditions [1]. For some fluids such as gas and steam, changes in fluid working conditions have a particularly large impact on the measurement accuracy and must be compensated. Different types of flow measurement devices measure different fluid media, and the mathematical models of temperature and pressure compensation formulas are different.

To solve these problems, the calculation unit of the unit combination meter can be used for calculation, or the various calculation function modules existing in the DCS and intelligent digital regulator can be used to complete the calculation. However, due to the different configuration methods and configuration parameters of various neural networks and digital

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regulators, the compensation accuracy also varies greatly. Therefore, it is necessary to analyze and study the mathematical model of temperature and pressure compensation in flow measurement, and summarize a new set of compensation methods, eliminate system errors as much as possible, and give full play to the powerful calculation functions of neural networks to improve the measurement accuracy to A new level.

Analysis of neural network mathematical model for steam flow measurement and compensation

In the measurement of steam flow, although density is also a function of temperature and pressure, it no longer follows the ideal gas state equation, and in different pressure and temperature ranges, the functional relationship is different. It is difficult to use a simple or unified functional relationship spoke. But in the process of neural network engineering configuration, in the low pressure range (such as less than 1 MPa), superheated steam can also use the ideal gas state equation for temperature and pressure compensation. But at high pressure, the influence of density change and compressibility must be considered. At this time, in order to measure the steam flow more accurately, the density determination method must be used to compensate [2]. The following two compensation methods are analyzed as follows.

Compensation method for temperature and pressure in ideal gas

In the low pressure range, the ideal gas state equation can be used to compensate the temperature and pressure of the gas medium. For superheated steam, it can also be used for actual gas treatment. For most gases, the compression factor in the low pressure zone is close to 1. In this zone, as long as the temperature is not too low, even if the compression factor is not corrected, it will not cause obvious errors, which can fully meet the engineering requirements [3]. The relationship between the mass-flow of gas and superheated steam and the differential pressure of the throttling device measured with a differential pressure transmitter can be expressed:

$$q^{Vn} = k\sqrt{o\Delta p^n} \tag{1}$$

Under actual working conditions, it can be expressed:

$$q^{V1} = k\sqrt{o\Delta p^1} \tag{2}$$

For a gas with a certain mass-flow rate, if only the effects of temperature and pressure changes are considered, according to the ideal gas law, we can get:

$$q^{Vn} = q^{m1}\frac{T_n p^1}{T_1 p^n} \tag{3}$$

where q^{Vn} is the mass-flow rate under the design basis conditions, q^{V1} – the mass-flow rate measured under the actual working conditions, T_n [K] – the temperature of the measured gas under the design basis conditions, T_1 [K] – the temperature of the measured gas under the actual working conditions, p^n [MPa] – the absolute pressure of the measured gas under design basis conditions, and p^1 [MPa] – the absolute pressure of the measured gas under actual working conditions.

For example, the reference conditions for hydrogen design of reforming hydrogenation unit: T_n =130 °C, p^n = 4.2 MPa(G), q^{Vn} =120 m^3/h, corresponding full-scale differential pressure transmitter Δp^n = 30 kPa. However, the actual operating temperature varies within the range of 80-180 °C, and the pressure varies within the range of 4.0-4.5 MPa(G). If temperature and pressure compensation are not performed and the differential pressure transmitter is also

30 kPa, the actual error of the hydrogen flow rate will reach about –10% to 8%. This result shows that when the fluctuation range of temperature and pressure is large, the measurement of gas-flow will introduce large errors, so the temperature and pressure compensation must be corrected according to the aforementioned formula. Superheated steam less than 1 MPa can also be corrected using the previous formula.

Equation (3) is the basic formula for measuring gas-flow temperature and pressure compensation correction, but since the unit of temperature in this formula is absolute temperature and the unit of pressure is absolute pressure, unit conversion is required in the calculation. That is, though $T = t + 2.73.16$, the temperature in °C is converted into the thermodynamic temperature scale K, and the gauge pressure $p(G)$ is converted into absolute pressure $p(A) – P(G)$ atmospheric pressure, 1 standard atmospheric pressure =101.3 KPa – 0.103 MPa. Therefore, eq. (3) can be re-written:

$$q^{Vn} = q^{V1} \frac{(t_n + 273.16)[p_1(G) + 0.103]}{(t_1 + 273.16)[p_N(G) + 0.103]} \tag{4}$$

where t_n [°C] is the temperature of the measured gas under the design basis conditions and t_1 [°C] – the temperature of the measured gas under actual working conditions.

Method of determining density

Most of the water vapor used in industry or engineering is in the state when it has just left the liquid state or is close to the liquid state. Its physical and chemical properties are quite different from the ideal gas and should be regarded as actual gas. The physical properties of water vapor are much more complicated than ideal gases, so they cannot be described by simple mathematical expressions. Therefore, in previous engineering calculations, most of the state parameter values involving water vapor were directly checked from the relevant water vapor table [4]. With the development of electronic technology, neural networks have been widely used in various chemical control processes, providing a powerful means for flow measurement, storage, and rapid and accurate calculation determine the density of water vapor.

Flow measurement and compensation of saturated steam

The differential pressure flowmeter is currently the main instrument for measuring saturated steam. When the throttle element is used as the sensing element in the steam measurement, the calculation method is used to compensate, and the flow formula is:

$$q^m = \frac{c\varepsilon}{\sqrt{1-\beta^4}} \frac{\pi}{4} d_0^2 \sqrt{2\rho_s \Delta p} \tag{5}$$

where q^n [kgh^{-1}] is the mass-flow of saturated steam, c – the outflow coefficient determined according to the design conditions, d_0^2 [mm] – the aperture of the orifice plate at the design temperature, ε – the gas expansion coefficient determined according to the design conditions, β – the joint ratio of the diameter of the flow piece to the inner diameter of the straight pipe section, $\beta = d/D$, Δp [Pa] – the differential pressure before and after the orifice, and ρ_s [kgm^{-3}] – the density of the measured fluid (saturated steam) under the design conditions.

After the flowmeter is installed, β, ε, c, and d are fixed values. When the operating conditions of the steam (pressure or temperature) change, set the steam density at this time as ρ. If the differential pressure before and after the orifice does not change, it is still Δp, and the flow becomes q^{m1} at this time:

$$q^{m1} = \frac{c\varepsilon}{\sqrt{1-\beta^4}}\frac{\pi}{4}d_0^2\sqrt{2\rho\Delta p} \tag{6}$$

Combining eqs. (5) and (6):

$$q^{m1} = q^m\sqrt{\frac{\rho}{\rho_s}} \tag{7}$$

The eq. (5) is to compensate the flow rate according to the density parameter. The density compensation of the steam flow rate must detect the density of the saturated steam at any time. Currently, there is no fixed density meter that detects the saturation density. The characteristic of one-to-one correspondence between the working temperature, the indication value of the flowmeter is indirectly corrected through the pressure or temperature parameters [5]. Generally, a table look-up method of calculation method is adopted to obtain the density value at a certain pressure and temperature.

Look-up table method

First, according to the temperature and pressure values under the design conditions, the corresponding saturated vapor density, ρ_s, is directly found from the water vapor density table as a constant of the neural network configuration.

Calculation method

We need to use the fitting formula of density compensation calculate the steam density, ρ, when the operating conditions (pressure or temperature) of the steam change in real time. The usual formula:

$$\rho = \frac{18.56p}{0.01t + 1.66 - (0.0001t + 0.02)p} \tag{8}$$

where t [°C] is the temperature and p [MPa] – the gauge pressure. The actual working conditions of steam: working pressure change range 0.1-1.1 MPa, working temperature change range 160-410 °C:

$$\rho = \frac{18.56p}{0.01t - 0.05608p + 1.66} \tag{9}$$

The actual working conditions of steam: the working pressure varies from 1-14.7 MPa. The working temperature varies from 400-500 °C:

$$\rho = \frac{19.44p}{0.01t - 0.151p + 2.1627} \tag{10}$$

According to the actual working conditions on site, a formula that is close to the working range of the density compensation fitting formula can be flexibly selected to achieve higher accuracy.

Ways and methods of ABB Industrial IT neural network configuration realize temperature and pressure compensation in steam flow measurement

The ABB Industrial IT control system, namely Freelance2000 system, is an all-round, comprehensive and open control system, which combines the advantages of traditional neural network and PLC, and supports multiple international fieldbus standards. It not only has the ability to adjust the complex analog loop of the neural network, friendly man-machine interface and convenient engineering software, but also has high speed logic and sequence control performance equivalent to high end PLC indicators.

The ABB Industrial IT control system is based on a real-time data acquisition system, including analog computing systems and intelligent real-time monitoring and optimization subsystems, as shown in fig. 1, and integrates chemical engineering, thermal energy engineering, computer and information engineering, computational mathematics, management engineering, and other disciplines are a set of the most advanced steam system simulation, analysis, monitoring and optimized operation system.

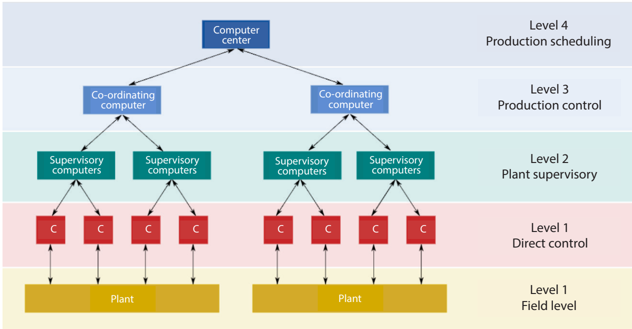

Figure 1. The ABB Industrial IT control system logic diagram

In the current production process, although a large amount of data is collected, these data are lagging and cannot reflect the current operating conditions. In addition, there is a lack of scientific analysis methods, so the utilization rate of these data is quite low (about 7%). The ABB Industrial IT control system makes the steam management dispatchers like a fish in the water, sorting and analyzing these complicated data, so as to help managers and operators make scientific assessments and decisions on the pipe network.

Project implementation process

Now, the realization process of the two algorithms used in the system (superheated steam) ideal gas compensation and saturated steam density determination compensation are introduced as follows.

Data collection process

According to the field survey, most of the steam system measuring instruments are smart meters produced by a certain company, and their model is XLF-51. Other meters are mostly meters with similar structures. In order to gather the steam system data together, it is necessary to establish a real-time database for the steam system, collect and save all the steam data, and connect with the relational database of the ABB Industrial IT control system to realize the integration of basic data and optimized data. Since this system involves the entire plant area and has a wide range of points, how to integrate all the steam system data into a real-time database is a very difficult problem [6]. When considering the introduction of data, the following principles are mainly followed:

– It is technically feasible. The introduction of data must first be ensured to be realized. This requires full consideration of the technical constraints of the instruments currently used and the instruments to be used in the future.
– On the premise of technical feasibility, economic feasibility and maintenance convenience should be considered.
– After considering the aforementioned two points, the need for future expansion of the system should also be considered.

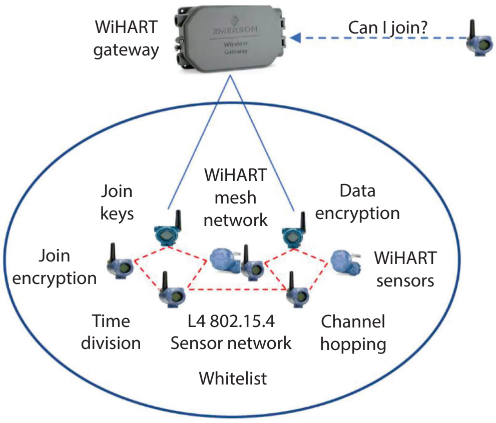

Figure 2. Steam system network topology diagram

– In order to measure the data more accurately, the best method is to collect all the signals directly from the on-site meter once, so as to ensure the reliability of the calculation results.

In view of the previous principles, the data collection of the steam system of the whole plant can be divided into 29 *T*-shaped stations according to the principle of nearby access. The system topology is shown in fig. 2.

The so-called *T*-type station means that the location of the instrument has been connected to the factory network, but the data of the instrument has not been collected on the computer. A virtual data collection station (as a relay station) is placed at the device point of the network connection. We call this data collection station, it is a *T*-shaped station. This collection station cannot only realize the communication with the secondary instrument, but also send the collected signal of the secondary instrument to the factory network [7]. A computer data acquisition station is set up in the central computer room of the comprehensive building. Through this data acquisition station, communication with all virtual data acquisition stations can be realized.

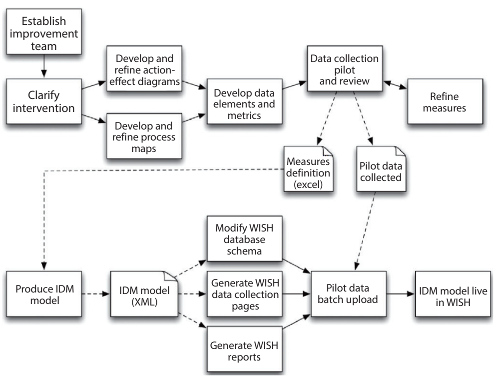

Figure 3. Data collection process

The signal of the primary meter is sent all the way to the secondary meter in use through the signal distributor, and to the ADAM data acquisition module all the way. The *T*-type station uses an ADAM4570S module, which introduces the collected data to the digital port of ADAM4570S through the RS485 protocol of the ADAM module. Then through the network interface provided by ADAM4570S, it can be directly connected to the computer, or it can be connected to the factory area LAN. Then the signal is directly introduced into the OPC Server data acquisition station through the network, thereby introducing the signal of the secondary meter into the real-time database. The collection method is shown in fig. 3.

In the process of signal debugging, the notebook computer is directly connected to the ADAM4570S module, and the ADAM 4000 Utility software is used to conduct simulation acquisition on site. This process is the foundation of the entire system, and the correctness of the collected signals is reflected in this process. Therefore, signal debugging in this process is particularly critical. In the process of signal debugging, the biggest problem encountered is the problem of signal type matching and the problem of accurate signal transmission.

In the process of signal transmission, the most basic principle is to maintain the one-to-one correspondence of signal types. From the primary meter in the field to the secondary meter in the operating room, and then to the ADAM data acquisition module, we must ensure that the I/O signals are of the same type. In the 141-metering station, the signal type received by the meter is 1~5 V, while the signal received by the data acquisition module is 4~20 mA, which has the problem of signal type mismatch. After consulting a large amount of data, it is found that this ADAM data acquisition module has a built-in jumper setting [8]. When the jumper setting is performed on it, the receiving signal of the data acquisition module is changed to 1~5 V. In this way, the unity of signal types is achieved and the signal transmission is guaranteed.

During the acquisition process, the signal is often attenuated. There are mostly two reasons: first, because the field signal is weak, but the transmission distance is relatively long, the signal is attenuated due to external influences; the problem is to use the principle of proximity as much as possible to introduce the signal to the nearest collection station and second, wrong wiring can also cause signal attenuation. In the 42/13 crude-oil operation room, the primary instrument on site is a three-wire vortex flowmeter, and the signal type is a frequency signal. The original design was to directly connect the data acquisition module to the signal end of the secondary meter [9]. Data can be collected, but after measurement, it is found that the signal has been attenuated by about half, so this wiring method is not advisable. We can only adopt the method of signal distribution. The signal from the scene is divided into two channels through the frequency signal distributor, one is distributed to the secondary meter, and the other is distributed to the data acquisition module. When using this method, pay attention keep the signal *ground* connected with the power *ground* of the primary meter.

Data collection supporting network

The collected data enters a port of the switch after coming out of the ADAM4570S interface. First, assign an IP address to this port of the switch and connect it to the server through optical fiber to ensure that the port and the server are connected to each other. According to this IP address, the ADAM gateway module 4570S is configured for address through the Configuration Utility program of EDGCOM Port. Then complete the port mapping work, start the EDGCOM Port Mapping Utility program, select unused ports in *Unused Ports*, select the corresponding module model, IP address, and port number to add, as shown in fig. 4.

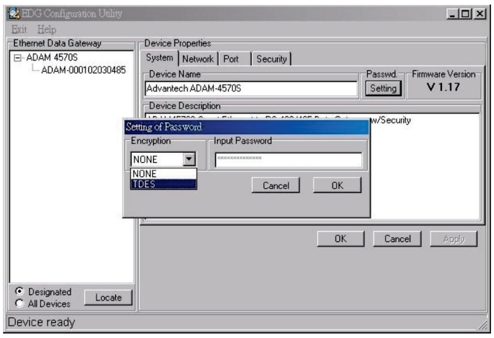

Figure 4. The ADAM 4570S mapping port

After the port mapping is successful, use OPC Server to collect the data of ADAM 4570S through the COM port, thus achieving a *T*-station data integration. If these 29 *T*-type stations are connected by optical fiber, and the data is collected into the real-time database of the server by OPC, then the data collection of the steam system is completed.

The ABB Industrial IT control system

The ABB Industrial IT control system uses the real-time data information of the steam system, inputs the intelligent model describing the pipe network, and obtains all the information of the entire pipe network system through simulation calculation [10]. This information reflects the operation mechanism and change trend of the entire pipe network, so that it can be Assist operators to propose smart solutions. The ABB Industrial IT control system enables the steam management dispatchers to organize the complicated real-time data of the steam system clearly, so as to assist the operators in making scientific assessments and predictions of the pipe network. The overall structure of ABB Industrial IT control system is shown in fig. 5.

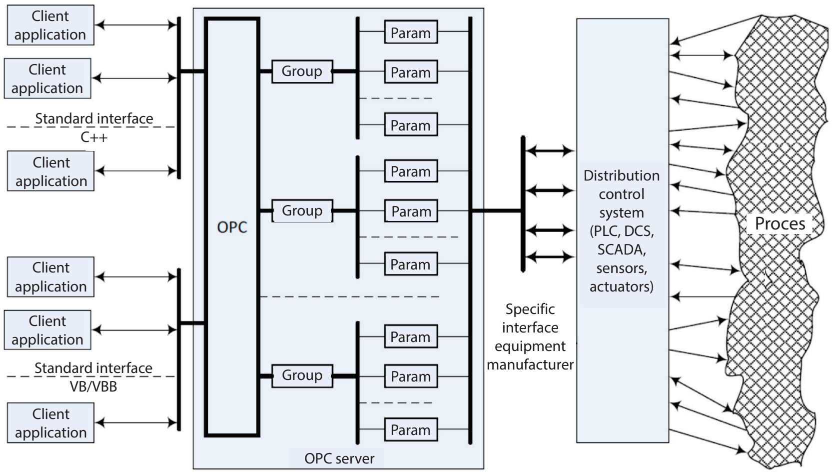

Figure 5. The ABB Industrial IT control system overall structure diagram

The data obtained from the measuring points are collected into a real-time database. The real-time database inputs limited operating parameters into CANAC Hydro Net through an interface program. The CANAC Hydro Net first performs temperature and pressure compensation correction on the input flow, and then passes through the mathematical model of the pipe network [11]. The calculation is performed, and the operating parameters after temperature and pressure compensation correction and the results of a large number of calculations are output to the real-time database through the interface program. The real-time database displays all the monitoring parameters required by the user on the main monitoring interface, allowing engineers, managers, workshop technicians and operators to monitor in real time and quickly respond to production requirements.

The temperature and pressure compensation configuration of ideal gas (superheated steam)

For the ideal gas (superheated steam) temperature and pressure compensation configuration process is relatively easy to achieve, using eq. (4). For example, the reference conditions for the design of the superheated steam FI-2416 of a reforming hydrogenation unit: t = 250 °C, p = 1.37 MPa, TI-2401, PIC-2412 as the temperature and pressure compensation measurement values of the steam flow. For such a typical compensation loop, it is relatively easy to implement in the Freelance2000 system. Although there is no special temperature and pressure compensation module in the system, the Control Builder F database software package of the system is flexible and convenient to configure and has complete functions [12]. It is very easy to configure the compensation principle and determine the corresponding variables and compensation formula.

Implementation process:

– First define the @FI-2416.PV, @TI-2401.PV, and @PIC-2412.PV, variables in the I/O card channel of the system, so that the system can collect in real time through the I/O card channel the signal value of the field transmitter, and convert the type of the value to real 141-metering.
– Use SCAL proportional module to perform range conversion and express it with FI-2416-SI; use SQR square root module to prescribe FI2416-SI.

- Use the SCAL proportional module to convert the value after the square root, and express it with FI-2416-S, the value is qV1 in eq. (4).
- Adopt ADD, MUL, and DIV (addition, multiplication, division) modules, respectively, and build the modules according to eq. (4) to complete the calculation tasks of eq. (4).
- The calculation results are in the FI-2416-A data monitoring module display. The configuration module structure is shown in fig. 6.

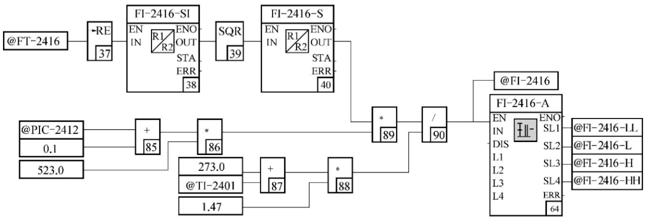

Figure 6. Configuration module structure of superheated steam temperature and pressure compensation

The temperature and pressure compensation configuration of the saturated steam density determination method

The temperature and pressure compensation configuration of the saturated vapor density determination method is more complicated, and three steps need to be completed:

- use the look-up table method to determine the saturated steam density ρ_s under the reference design conditions as a configuration constant,
- select the fitting eq. (8) that meets the actual working conditions, and design the corresponding algorithm module in the neural network database; carry out real-time calculation of the saturated steam density ρ under actual working conditions, and
- design the algorithm module of eq. (5) in the database, and substitute ρ_s, ρ has known variables into the module to obtain the compensated flow.

For example, the reference conditions for the design of saturated steam FI-2124 of a certain device: tn = 250 °C, $pn(G)$ = 0.8 MPa, TI-2104.PV, PIC-2106.PV as the temperature and pressure compensation measurement values of the steam flow, respectively. For such a typical saturated steam compensation circuit, the realization path and method in the neural network are basically similar to those in section *The temperature and pressure compensation configuration of ideal gas (superheated steam)*, except that the process of using ADD, MUL, and DIV modules is slightly more complicated. The configuration module structure is shown in fig. 7.

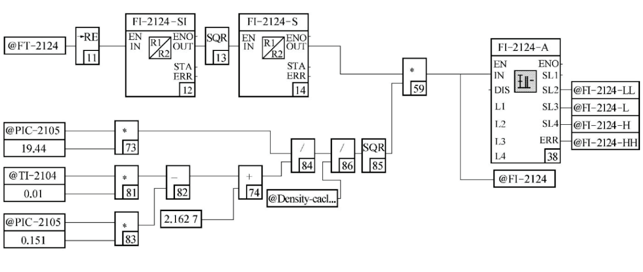

Figure 7. The temperature and pressure compensation configuration module structure of the saturated steam density determination method

Conclusion

When we choose the appropriate temperature and pressure compensation formula, we must fully understand the flow measurement method. When the measuring medium and working conditions are different, the correct temperature and pressure compensation method can be used to obtain the accurate flow rate. At the same time, we make full use of the powerful and flexible calculation function of neural network, apply the thermodynamic properties of traditional saturated steam, analyze and summarize a new set of compensation methods, eliminate system errors as much as possible, and calculate temperature changes (pressure changes) quickly and accurately. The density value of the fluid improves the accuracy of flow measurement.

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