The Research of Dynamic Calibration for Temperature Sensors

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Abstract. The current situation of temperature sensor dynamic calibration, including its conception, features and methods of data processing, are introduced in this paper. Especially the research on methods of dynamic calibration is conducted. The choice of calibration devices and several methods of result assessment are given. According to the methods introduced in this paper, the thermal wind tunnel method can generally satisfies performance requirement of temperature sensors and simulate practical working status of temperature sensors in specified experimental conditions. Therefore it is the best method of temperature sensor calibration at present.

1. Introduction

In present temperature measurement study, the common situations are transient temperature measurements especially in military applications. The character of transient temperature measurement is measuring in gas with high temperature and high velocity. It is possible that high pressure or high speed flow exists according to different conditions. So it is difficult to guarantee the measurement accuracy. Now system errors certainly exist in common methods, it is necessary to survey system errors of all sorts of sensors result from heat inertia and heat equilibrium with the methods of dynamic calibration. In this way it can makes measurements closer to the true value.

With the high speed development of science and technology, especially in the domain of aviation and aerospace (the aeroengine, rocket, jet technology etc.), temperature's rapid and accurate measurement has become much more important. In some circumstances, for example, the engine's start, acceleration and shutdown, the stalling and surging of gas compressor, the temperature changed rapidly, the sensor should immediately perceive the change of temperature, and effectively track the temperature's transformation. All of contacted-measure temperature sensors have heat inertia, and the characters of heat response are different. So the practical measuring temperature is a random function, especially in the fluid dynamic environment, only increasing temperature sensor's precision in stable conditions can't satisfy the requirement of measurement. How to reduce heat inertia and improve capability of measurement rapidly and accurately lead the development direction of temperature measurement nowadays. Only by enhancing sensor's thermal response characteristic and calibrate it, can it be possible to meet the requirement of dynamic measurement [1].

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In recent years, many research institutes have conducted temperature sensor dynamic calibration research. Because dynamic calibration of temperature sensor also relate to the environment in which they are used, so it makes certain differences in dynamic calibration of temperature sensor in many research institutes.

2. Research actuality of dynamic calibration of sensor

2.1. Domestic and foreign research situation

The research of dynamic character of sensor is always an active subject in academic field. In recent ten years, the research has changed from applying to military field to civil fields and it has made that more and more people begin to conduct research about dynamic character of sensor.

It has been a long time to conduct the research about temperature sensor dynamic calibration overseas and involved in broader areas. Many countries such as America, Russia, Germany and India have already achieved high level, but they don't share their achievements. In recent ten years many domestic institutes and universities have made deep research about the dynamic calibration of sensor and obtain satisfied results.

2.2. Concept of dynamic calibration

When the temperature of gas stream changes, such as rise or depress abruptly, we call it dynamic temperature. When the temperature sensor measures dynamic temperature, it can't reflect the changes of the temperature of gas stream rapidly because of its certain mass and heat inertia.

The dynamic response characteristic of temperature sensor means the relation of the temperature of sensor itself and increment of temperature being measured. We usually express them with differential equation or transfer function. As the temperature being measured changes in different forms such as step signal, impulse, or sine wave, the response to sensitive element of temperature sensor can reflect the dynamic characteristic of the sensor. So we often describe the dynamic characteristic of sensor with its response to step temperature and define two parameters, thermal response time and time constant, to reflect the dynamic characteristic. The quality of dynamic characteristic directly reflects the tracking ability of sensor on temperature changing over time.

Dynamic calibration of temperature sensor is a process of record and calculation. First the sensor's response to step signal under certain conditions is measured, and then, the thermal response time or time constant will be calculated through the tracking record in the response process. Calibration process mainly include generation of stable calibration conditions (stable velocity field and temperature field), making the temperature sensor accept the temperature step signal stimulation, collection of being calibrated sensor's response to step signal by testing system, calculating the thermal response time or time constant. The two parameters not only relate to structure, material, using conditions of the sensor, but also relate to flow stream being tested and calibration conditions.

2.3. Content of dynamic calibration

Dynamic calibration of sensor mainly include two factors.

2.3.1. Dynamic demarcate. Because sensor is widely used in automatic inspect of produce process, new type of sensors are continuously manufactured. In order to know the dynamic characteristic of sensor accurately, we need to conduct the dynamic demarcate.

2.3.2. Dynamic proofread. After a long-term use there will be some problems in the sensor or home-made sensor such as time float, temperature float, or some parameters changed. All these phenomena can result in sensitivity or zero position changed obviously. So it must be dynamic proofreaded for sensor [2].

2.4. Method of improving the dynamic characteristic

To improve the dynamic characteristic of sensor is the ultimate purpose of dynamic calibration. It can be considered through the two aspects of production and use [3].

2.4.1. View point of production—dynamic compensation analog filter. The manufacturer can encapsulate the specialized chips made of modulated analog filter, sensors and amplifying circuit conveniently. This will improve the dynamic characteristic of sensor radically from hardware. The capability of sensor will be enhanced which manifests as rapid calculation speed, small volume, rapid response and high resolution.

2.4.2. View point of use—dynamic compensate digital filter. If the dynamic characteristic of temperature sensor is getting worse, it is useless to adopt the method of dynamic compensate analog filter. The dynamic characteristic of testing system has to be improved by using computer and software methods. Through compiling simple compensate digital filter program, the entire channels dynamic characteristic will be enhanced a lot without adding any other hardware.

To a common user, the second method is usually used to ameliorate the dynamic characteristic of sensor.

3. Calibrating apparatus and methods

The two aspects introduced above apply to all sorts of sensors. Some special circumstances of calibration will be discussed next.

3.1. Experimental research method of calibration

There are many methods to research the dynamic calibration of sensor in experiment conditions and five of them will be introduced in this article.

3.1.1. Traditional standard experimental method: plunge into experimental method. When the thermocouple at a stable original temperature is plugged into different temperature field, a step temperature will be generated. And at the same time continual response of thermocouple will be recorded. Normally the temperature sensor being calibrated will be plug in thermostabilized cistern or oil tank rapidly and result in a step temperature stimulant. By this way it can only produce less step temperature, and it can't satisfy the dynamic calibration on spot. To the temperature sensors with little time constant, this method usually can't meet the requirement.

3.1.2. Transient electric heating method by using thermocouple. When the thermocouple at a stable testing temperature is heated up by using electricity, the temperature of hot junction will increase instantaneously because of the resistance of thermocouple itself. When the thermocouple is placed in the testing airflow and the electric heating power is higher than the heat dissipation power, the temperature of thermocouple will increase gradually until it's higher than temperature of testing airflow. Then shut off the power supply and place the thermocouple in the former testing airflow again. In this way the input of thermocouple is a negative step signal, and the response of thermocouple will be recorded at the same time [4].

This method can apply to calibration on measurement conditions, but also apply to measurement of time constant of thermocouple which has little heat inertia. But this method is not appropriate to single-shield temperature sensors because it can't measure how the shield case affects the dynamic characteristic of temperature sensors [5].

3.1.3. Shock wave pipe method. Shock wave pipe is an experimental equipment which can produce step pressure. Research on the characteristic of gas flow in the shock wave pipe indicated that there is a temperature step platform behind the incident shock wave front. So shock wave pipe can be used in the temperature calibration experiment. Time constant of temperature sensors can be attained by recording the step response curve of testing sensors. This method is an attempt to dynamic calibration experiment on thermocouple which has little time constant in recent years. But the problem of this method is that temperature step platform only holds a short time, so it is not enough to make the output response of temperature sensors stable and time constant can't be attained either [6].

3.1.4. Laser method. In this method laser impulse is used as a dynamic stimulating signal and generating instantaneous temperature increase when emitting to the surface of sensors. Once the laser impulse is taken away, temperature sensors will produce negative temperature step in the stable gas flow. In this way the delay time of generating temperature step is short and satisfying and all the modalities of being calibrated system can be covered by frequency spectrum of stimulating signal. But this method has the same defect as transient electric heating method [7].

3.1.5. Thermal wind tunnel method. In this method stable high-temperature gas stream which is generated by both wind tunnel and heater will be blended with normal-temperature gas stream which is generated by wind tunnel, and then place the sensor in the blended gas stream. Temperature step signal will be generated by popping up a stream of gas suddenly through the ejection device.

This method generally satisfies performance requirement of some certain temperature sensors and it has unique advantage that practical conditions of temperature sensors can be simulated on experimental conditions.

3.2. The Device and method of wind tunnel calibration

3.2.1. Temperature sensor calibration device. The mainly calibration device include normal-temperature calibration wind tunnel or high-temperature calibration wind tunnel, temperature step signal system, reference temperature sensor, testing device, etc. Temperature step signal system produce step temperature for the testing environment. High-temperature calibration wind tunnel can generate a positive step temperature by using shielded ejection mechanism and cold gas stream. Normal-temperature calibration wind tunnel can generate a negative step temperature by using ejection mechanism and hot gas stream or laser device.

3.2.2. Method of calibration. Schematics of dynamic calibration of temperature sensors for normal-temperature calibration wind tunnel and high-temperature calibration wind tunnel are shown as Figure 1 and Figure 2. Normally calibration wind tunnel device simulates the working conditions of temperature sensor and provide gas stream circumstance with stable and even flow field and temperature field. And then extent of step can regulate to the required value when giving the temperature sensor being calibrated a temperature step change. The total pressure and total temperature and static pressure in the wind tunnel measured by the pressure sensor and reference thermocouple, atmospheric pressure measured by mercury-free barometer will be transformed by the 912 module and collected by computer. Finally the gas stream Mach number and velocity of mass stream can be calculated. The methods of generating temperature jump are mainly included method of producing temperature step through laser device and method of changing environment temperature of temperature sensor which is usually used. First, regulate the flow of cold gas stream and make the temperature sensor being calibrated reach the temperature point before step temperature, then flick away the cold gas stream by using ejection device and expose the sensor into hot stream. On these conditions above, temperature positive step on measurement point will be formed. The voltage signal of temperature sensor being calibrated will be recorded by digital storage oscilloscope after filtering

by amplifier. The temperature step response curves of temperature sensor on the same experimental conditions will be repeated three times. On the curves we can find the required thermal response time and time constant by using direct graphic method. According to collected response curves (data), we can also build appropriate mathematical models, fit the formula and calculate the time constant or thermal response time.

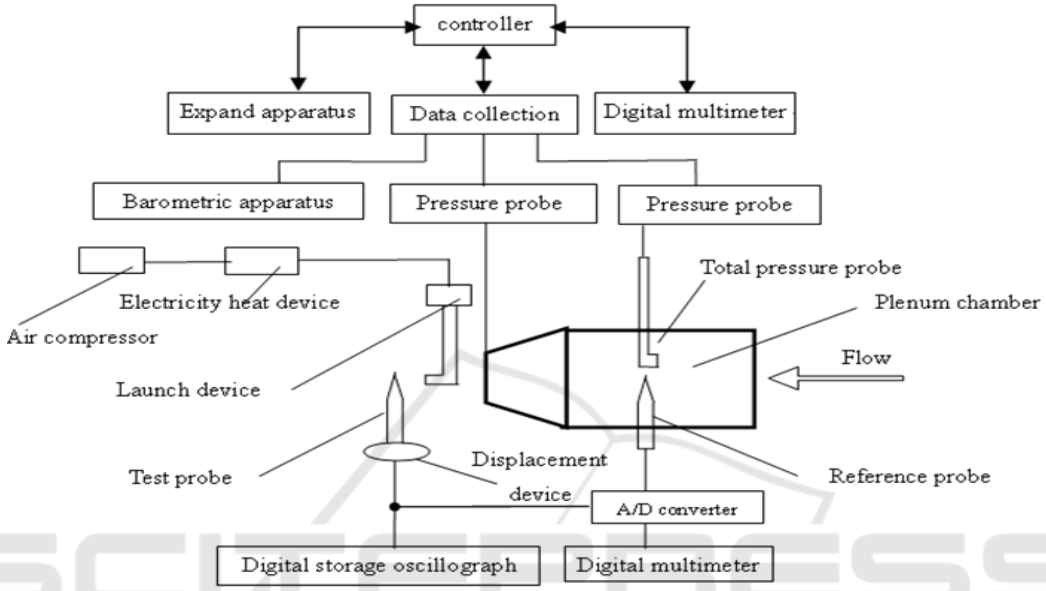

Figure 1. Dynamic calibration frame of normal-temperature wind tunnel.

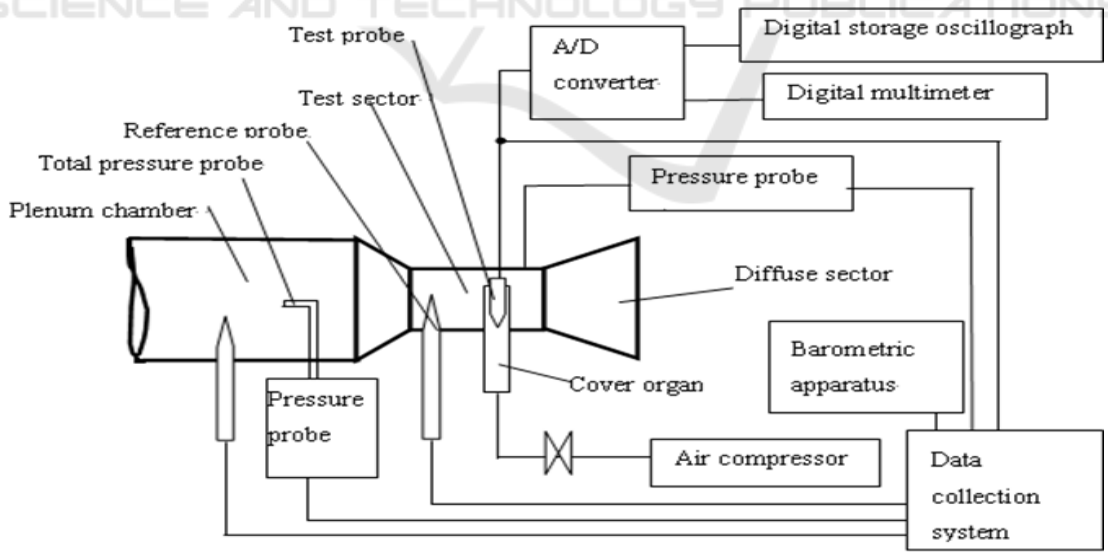

Figure 2. Dynamic calibration frame of high-temperature wind tunnel.

3.2.3. Data processing of calibration. The calculation stream Mach number formula is:

$$M = \sqrt{\frac{2}{\kappa - 1}\left[\left(\frac{p_0}{p_s}\right)^{\frac{\kappa-1}{\kappa}} - 1\right]} \tag{1}$$

Where κ means combustion gas, κ=1.33.

Velocity of mass stream G can be calculated as follows:

$$G = M \cdot Ps \cdot \sqrt{\frac{\kappa}{RT}} \tag{2}$$

In the formulas above, static temperature of gas stream can be calculated as follows:

$$T = \frac{t_0 + 273.15}{1 + \left[\frac{\kappa - 1}{2} M^2\right]} \tag{3}$$

Voltage-time response curves can be recorded by digital storage oscilloscope. On the curves we can find the time constant $\tau_{0.632}$ corresponding to the point of 63.2% step and this time constant can be the time constant of the sensors [8].

3.3. Appraisal of dynamic characteristic calibration

There is not uniform standard to appraise the dynamic characteristic calibration of temperature sensors at present. It is often evaluated from several aspects as follows.

3.3.1. Parameter of dynamic characteristic: time constant, transmission bands, working bands, built-up time, etc. The time constant of temperature sensor can be detected easily and intuitively because the sensor is often considered as first-order system. But the input signal can't be regard as step signal totally no matter how it is processed [9], so there must be some certain errors in the dynamic characteristic.

3.3.2. Building the dynamic mathematic models. Spectral analysis can be conducted according to the dynamic mathematic models of temperature sensors.

3.3.3. Examine the repeatability and linearity of dynamic characteristic of temperature sensors. The repeatability and linearity are introduced because temperature sensor is not always in ideal condition. Dynamic repeatability represents the precision of repeated dynamic calibration. Dynamic linearity represents how the dynamic stimulation signal in whole range of temperature sensor affects dynamic calibration.

3.3.4. Analysis of uncertainty. It is the basic requirement for measuring technique nowadays that measuring result should be given in each measurement and analysis of uncertainty should be conducted according to measuring result. If the time constant is the final result on dynamic calibration, it can be analyzed according to ISO1993 (E) <Guide to the Uncertainty in Measurement>. But in many conditions the processing of dynamic characteristic response function can't be conducted effectively.

According to the factual circumstances process analysis, it can consult the above methods to appraise result of the dynamic calibration.

4. Conclusions

In the research of dynamic calibration of temperature sensors, there is no definite conclusion about many issues which should be discussed further in the studies later.

4.1. Appraise standard of stimulation signal (for example step signal)

It is impossible to attain the ideal step signal in any way in the dynamic calibration experiment. So it is necessary to conduct more research on the relationship of requirement of stimulation signal and temperature sensors being calibrated.

4.2. Appraise methods of dynamic calibration

In this paper the commonly used appraise methods about dynamic calibration are given. But these methods place emphasis on different aspects. How to unify these methods or create a new and comprehensive method is a problem that needs urgent resolution. This is the only way all sorts of model sensors can be conveniently compared with.

The dynamic calibration of temperature sensors, including its conception, characteristic and methods of data processing are discussed in this paper. Especially the research on methods of dynamic calibration is conducted. Because the thermal wind tunnel method can generally satisfies performance requirement of temperature sensors and simulate practical working status of temperature sensors in specified experimental conditions, so it is the best method of temperature sensor calibration at present.

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