Design of MEMS Temperature Sensor for High Voltage Switchgear

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ABSTRACT

Firstly this paper introduces the traditional switchgear temperature measurements, including the empirical method, infrared temperature measurement, optical fiber temperature measurement, SAW temperature measurement, low power sensor temperature measurement, microelectronic device temperature measurement, which focuses on the different principles and features of the method, and conducts feasibility analysis of the practical application of measuring the switchgear temperature rising effect. Finally, a micro-electro-mechanical system (MEMS) sensor design based on micro-nanoelectronic process is proposed, which is the piezoresistive cantilever MEMS temperature sensor. The main design parameters of the sensor determined by COMSOL simulation and sensor processing technology are invented.¹

INTRAODUCTION

Large-capacity switchgear is regarded as an important device in power plants and substations. The isolation contact and busbar connection as well as other conductive connections in the switchgear lead to too large contact resistance and fever due to aging and other reasons during long-term running process. Long-term fever may cause short circuit accident and even fire disasters eventually, thereby seriously affecting power supply reliability of the power grid. Currently, temperature

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measurement methods commonly used at home and abroad include contact and non-contact temperature measurement.

In this paper, most existing switchgear temperature measurement plans are summarized. There is no effective real-time on-line monitoring method for the overheating problem of the conductive connection. MEMS temperature sensor becomes the preference plan of switchgear online temperature measurement due to its advantages compared with other temperature measurement plans.

TRADITIONAL TEMPERATURE MEASUREMENT METHODS

Empirical Method

The traditional empirical temperature estimation methods include the follows: wax-scale pasting, smell judgment, abnormal sound judgment, cabinet door temperature touching, etc. Those methods are characterized by inaccurate measurement. The switchgear operation state and temperature in the cabinet cannot be reflected completely and accurately in real time.

Infrared Temperature Measurement

The infrared thermometry can be further divided into two temperature measurement methods of infrared imaging temperature measurement and infrared probe temperature measurement. Both methods are non-direct contact measurement methods. The infrared imaging temperature measurement is based on the principle of black-body radiation law. Any object higher than absolute zero degree can emit radiant energy. The temperature on the surface of the object is reflected by the size of object infrared radiation energy and distribution of wavelength. Therefore, the surface temperature of the object can be determined by measuring the infrared radiation energy size of the object. The sensor is used for detecting the infrared radiation emitted by the object, and the radiation energy can be turned into electrical signals. The temperature on the surface of the tested object can be obtained finally through calibration operation [1].

Optical Fiber Thermometry

Temperature signals are transmitted by optical fiber according to optical fiber thermometry, including contact temperature measurement and non-contact temperature measurement. The contact temperature measurement principles include grating principle and scattering principle. Grating optical fiber temperature measurement is based on the Bragg grating principle. It refers that the light emitted from broadband light source passes through optical fiber grating, and then it can be reflected according to specific center wavelength. The center wavelength varies linearly with temperature change. The principle can be utilized for packaging optical
fiber grating into sensor probe for testing temperature change. Distributed optical fiber (DTS) temperature measurement is based on the principle of Raman scattering, namely optical wave is regarded as electromagnetic wave for transmission in medium, which follows the Maxwell's equations. It is related to medium properties. The principle is utilized for measuring temperature change along optical fiber. It has excellent advantages in long-distance distributed temperature measurement such as cable, etc. [2].

**Surface Acoustic Wave Temperature Measurement**

The surface acoustic wave wireless temperature sensor consists of an antenna, an interdigital transducer, a reflecting grating and a piezoelectric substrate. The temperature measurement principle is shown as follows: the surface acoustic wave on the surface of the piezoelectric substrate is transmitted. Its wavelength and wave velocity will be changed with the change of the substrate surface or internal related factors (including temperature) [3-4]. After the transducer on the piezoelectric crystal substrate is used for converting input wireless signals into sound signals by inverse piezoelectric effect, and the signals are reflected by the two periodic grid bars on the left and right to form resonance. The resonance frequency of the resonator is related to the temperature of the substrate. In addition, the change of the resonant frequency with temperature change shows a linear relationship within certain range of temperature.

**TABLE I. COMPARISON OF ON-LINE TEMPERATURE MEASUREMENT TECHNIQUES.**

| Thermometry type | Optical fiber thermometry | Infrared thermometry | Low power consumption chip thermometry | Surface acoustic wave thermometry |
|------------------|---------------------------|----------------------|----------------------------------------|----------------------------------|
| Temperature measurement features | Contact temperature measurement | Non-contact temperature measurement | Contact temperature measurement | Non-contact temperature measurement |
| Temperature measurement accuracy | ±0.5°C | -∞ | ±0.5°C | ±1°C |
| Temperature measurement range | -40~200°C | -∞ | -25~125°C | -20~125°C |
| Structure size | 25×2.6×2.6mm² | -∞ | 50×34×33mm² | 30×15×10mm² |
| Economy | Poor | Poor | Good | Poor |
| Safety | General | Poor | General | General |
| Reliability | Good | Poor | Good | General |
| Construction difficulty | Difficult optical fiber wiring | Fixed support is required for installation | Simple installation | Simple installation |
Microelectronic Device Temperature Measurement

At present, there are several following microelectronic temperature measurement devices.

1) Platinum thermistor: good linearity, high repeatability, high stability, wide temperature range and inconvenient integration;

2) Semiconductor thermistor: it is divided into positive temperature coefficient thermistor and negative temperature coefficient thermistor;

3) Thermocouple: constant temperature point for reference should be given, which is frequently used for circuit temperature measurement on the chip. It is not used for environmental temperature measurement;

4) Silicon-based integrated thermal diode and triode: It is compatible with IC process. However, the temperature measurement scope is relatively narrow (-50 ~ 120 °C). It is commonly used in circuit temperature measurement on the chip rather than environment temperature measurement.

Summary

The traditional method of temperature measurements have respective advantages and disadvantages, which can't meet the demand of current large-capacity switchgear on real-time temperature measurement. We must seek other feasible plans in order to realize the temperature monitoring of contacts and busbar connections in high voltage switchgear. Several thermometries are compared and summarized in table I.

MEMS TEMPERATURE SENSOR

MEMS temperature sensor has outstanding advantages of high accuracy, high reliability, high noise immunity, high isolation potential level and convenient probe layout. It has advantages in the aspect of switchgear transient failure state warning. The temperature sensor based on MEMS technology can compensate for current energy supply problem low power consumption sensing chip thermometry. Independent temperature measurement is realized through non-contact energy supply. However, there is no application case about MEMS system aiming at sensing systems arranged in large-capacity switchgear. The technology is in the research and development stage. In addition, MEMS sensor system packaging and power supply problem in large-capacity switchgear still should be solved.

Temperature Measurement Principle

There are various plans for MEMS temperature sensors, such as two-layer thin-film silicon microbridge pressure resistance MEMS temperature sensor [5], resonant MEMS temperature sensor [6], capacitive MEMS temperature sensor [7], etc. In the
paper, cantilever piezo-resistive MEMS temperature sensor is introduced in details. Cantilever piezo-resistive MEMS temperature sensor is composed of a double-layer membrane structure. The upper layer is made of metal Al, the lower layer is made of Si on the SOI device layer (Silicon-On-Insulator namely silicon on insulating substrate). The thermal expansion coefficient of metal aluminum is about 10 times compared with that of silicon. When the ambient temperature of the cantilever is changed, the aluminum film deformation is larger than that of silicon, and the cantilever is bended. Wheatstone bridge is formed on the surface of Si. The resistance value in the wheatstone bridge is changed and when the cantilever is bended [5].

Determination of Sensor Structure Parameters

The maximum temperature is 125 °C or so during switchgear internal fault according to the experience of field running. It is expected that the position of resistance in the sensor can reach the stress of 100MPa during simulation in order to get better sensitivity. The resistance is about 20μm to the fixed end of the cantilever. COMSOL software is utilized for simulation and determination as shown in figure 6. The length of the cantilever is L=500μm, the width is W=50μm, Al film thickness is t1=1.5μm, and Si thickness is t2=8μm as shown in figure 1. The simulation results shows in figure 2.

Sensor Processing Flow

General flow is shown as follows: (1) selection of N-shaped resistance SOI; (2) ion implantation of boron fluoride (BF), the process is shown as follows: the element ions accelerated by the electric field is injected into the surface of the solid material at a certain speed for forming adulteration. The injection method is characterized by high accuracy, high purity and expensive cost. Thermal annealing process is always required after ion implantation, namely it should be annealed for 15 to 30 minutes under 950°C high temperature nitrogen protection, thereby eliminating damage due to injection and activating injected impurity ions. Damage also can be reduced through making the ions penetrate through the thin oxide layer. (3) Determination of contact hole (conductive terminal); (4) Formation of oxide layer and sputtering of Al; (5) Coating of polyimide (PI) on the right side for adhesive solidification; (6) negative etching, hollowing and release of cantilever [8-9].

CONCLUSIONS

In the paper, current temperature measurement plans of power system high voltage switchgear as well as advantages and disadvantages of these temperature measurement methods are discussed. It is discovered by comparison that these plans
can not meet the demand of current power system high voltage switchgear. Therefore, MEMS temperature sensor plan is proposed. Several sensor plans are considered comprehensively.

In the paper, the piezoresistive cantilever beam temperature sensor is introduced in details. The sensor parameters are determined through simulation. Processing flow in the production process is given briefly, and the subsequent work include sensor production and performance analysis on the process line.

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