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Simulation Analysis Method of Internal Temperature Distribution in UHV DC Voltage Measuring Device

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Abstract. The measuring accuracy of UHV DC voltage measuring device has a great relationship with the temperature. It is necessary to study the internal temperature distribution of the device to ensure that the operating device could meet the accuracy requirement in the temperature range. Firstly, the device dynamic thermal flow field is analyzed in this paper. The flow field model is established. Through analyzing the calculation model, the internal temperature distributions under different environment temperatures is obtained. And then, the internal temperature rise at the rated voltage is measured directly by experiment. And the validity of the model is verified by the experiment. This paper introduces the details of the method. By studying the internal temperature distribution of the device, the temperature range in which the device is running is gotten. Suitable resistive elements should be chosen during the design so as to meet the measuring accuracy of the device.

1. Introduction

UHV DC voltage measuring device is indispensable to the main equipment of converter station of DC transmission system, which undertakes the important functions of DC energy metering, power monitoring and signal protection for power system relay. In the design of UHV DC voltage measuring device, the parallel connection of resistance and capacitance is widely used [1].

In this paper, the UHV DC voltage measuring device rated voltage is ±800kV, the operating current is 2mA, DC voltage measuring accuracy is 0.2%, and the principle is the resistance and capacitance in parallel [2]. The structure of the device is an outdoor pillar type, which is composed of an external high-voltage insulator and an internal high-voltage resistance-capacitance device and is filled with SF_6 insulating gas. High and low voltage end shielding rings are arranged outside the insulator. High voltage double ring shielding and low voltage end single ring shielding are used to improve internal External electric field, the total height of the device is about 10 m, the structure diagram is shown in figure 1.

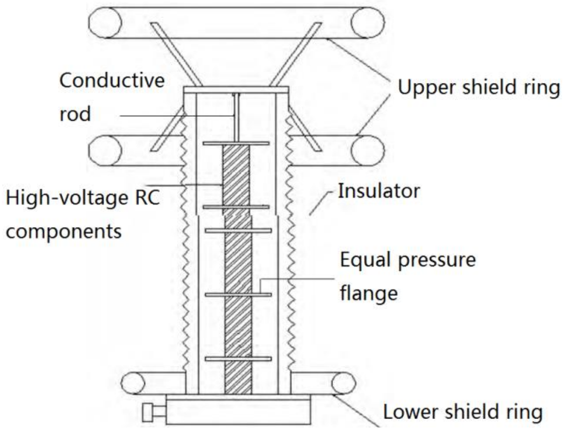

Figure 1. UHV DC voltage measuring device.

Relevant standards made it clear that the voltage divider resistor of measuring device should have sufficient thermal stability to ensure that the device within the specified temperature range of measurement accuracy to meet the requirements [3]. Measurement accuracy of the voltage divider depends largely on its voltage coefficient and temperature coefficient. It can be known from the design parameters that when the rated voltage of the device is operated, the power is 1600W, and the internal temperature of the device may have a certain temperature rise due to its own power heating [4]. By studying the internal temperature distribution of the device, the temperature range of the device operating at different ambient temperatures is obtained. In the design and manufacturing of the device, the suitable resistor and capacitor components can be selected more specifically. The temperature distribution inside the device is studied by establishing the flow field calculation model, analyzing and calculating the temperature distribution of the model under different ambient temperatures, and finally validating the calculation model of the flow field through experiments. Application of the manufacturing process model can be used for the selection of resistors, capacitors and other devices to provide reference to ensure that the device in the operating temperature range to meet the accuracy requirements to improve the reliability of product operation [5].

2. Establish a dynamic flow field model

2.1. Device thermal balance process

During the operation of the device, the internal resistance consumes power to generate heat. A part of the heat is first transferred by the internal gas to the inner walls of the upper and lower metal flanges of the device body in a manner of natural convection heat transfer, and then heat conduction from the inner wall of the upper and lower flanges to the outer wall, and ultimately convection heat transfer from the outer wall of the upper and lower flanges to the air outside the device; The other part of the heat is first transferred from the internal gas to the inner wall of the insulator of the device body, and then heat conduction from the inner wall of the insulator to the outer wall of the insulator, and finally from the outer wall of the insulator and the composite jacket to the air outside the device [6]. When the heat balance is reached, the internal temperature of the device would no longer changes, and all the heat generated internally is transmitted to the air outside the device.

2.2. Establishment and Analysis of Flow Field Model

SolidWorks and ANSYS DesignModeler are used to build the model [7]. Mesh is divided into two parts by using ICEM-CFD. FLUENT is used to calculate the pre-processing calculation. After calculating and solving, the data are processed. Finally, the flow velocity and temperature distribution of each part of the model are obtained. In the simulation calculation, CFD method is used to complete the flow heat transfer analysis, and FLUENT software is used to calculate.

To build the structural model used in the calculation, the original SolidWorks model was processed using ANSYS DesignModeler. The influence of umbrella skirt structure on overall flow and heat exchange is considered in the modeling, and the bracket to which the pressure equalizing ring is connected to the flange is simplified, and the features such as the smaller chamfer and the bolt hole on the flange at all levels are canceled. After the structural model is established, the model is imported into ICEM-CFD for meshing. The overall computational domain and the solid domain mesh are shown in figure 2 and figure 3, respectively.

Figure 2. Whole structure mesh generation.

Figure 3. Solid region mesh generation.

According to Figure 1, the device consists of a high voltage RC unit (single-layer voltage divider module), brackets, flanges, insulators, umbrella skirts and equalizing rings. The material parameters of each component are shown in table 1, and the conservative 25 °C solid material property is used as the input of calculation for the analysis [8].

Table 1. Material parameters of components.

Parameters	Bushing/ Capacitor/ Bracket (Insulation Material)	Resistor	Flange (aluminum)	Umbrella skirt (silicone rubber)
Specific heat/ [J (kg °C)$^{-1}$]	800	1090	871	1700
Thermal conductivity/ [W (m °C)$^{-1}$]	0.175	20.00	202.40	0.270

The physical properties of the air and SF_6 used in the calculation of the fluid field are given in table 2. Due to gravity-driven natural convection in and out of the device body, natural convection is simulated using the actual temperature-density relationship of air and SF_6. For viscosity, specific heat capacity, thermal conductivity and other parameters, only the properties at room temperature are considered in the calculation [9].

Table 2. Physical properties of air and SF_6.

Physical properties	Air	SF_6
Viscosity/ [Pa s^{-1}]	2.190×10^{-5}	1.211×10^{-5}
Specific heat/ [J (kg °C)$^{-1}$]	1009	634
Thermal conductivity/ [W (m °C)$^{-1}$]	0.0317	0.0106
Density (temperature/°C)/ [kg m^{-3})]	1.25(10°C)/ 1.09(50°C) 0.95(100°C)/ 0.85(140°C)	24.56(-23°C)/ 23.44(27°C) 14.04(227°C)

The flowing process of the external flow field is analyzed by the heat transfer characteristics of the model device. The air is heated vertically by the outer wall of the device and flows at an increasing speed. When the air flows through the voltage equalizing ring, the flow channel is compressed, making the pressure ring near the air flow rate increased. Since the thermal conductivity of the insulator is inferior to that of the metal flanges at the upper and lower ends, and the air velocity is

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relatively high, the temperature of the air outside the flow field is slightly higher than the ambient temperature. Outflow velocity distribution is shown in figure 4, the flow field temperature distribution is shown in figure 5.

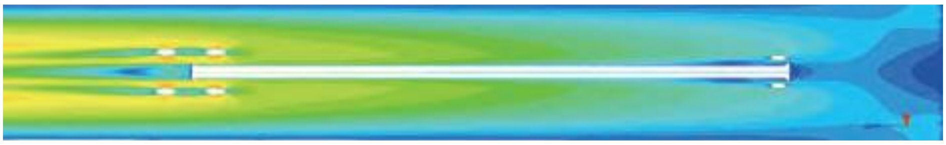

Figure 4. Velocity distribution of external flow field.

Figure 5. Temperature distribution of external flow field.

The flowing process of internal flow field: Due to the blocking effect of multi-layer voltage equalizing flanges, the SF_6 gas in the internal flow field presents a small cycle of disconnection so as to realize the heat exchange between the heat generating body and the inner wall of the insulator. The temperature of the resistor body in the single-layer voltage divider module is highest, followed by the flange and the capacitor, mainly because the resistor is the only heat-generating element. In addition, the temperature distribution in the vertical direction of the partial pressure modules is low in the lower part and high in the upper part. The main reason is that the hot SF_6 gas always flows upward from the lower part while the outside air temperature in the lower part of the device is lower than that in the upper part. The velocity distribution of the inner flow field is shown in figure 6, and the temperature distribution of the inner flow field is shown in figure 7.

Figure 6. Velocity distribution of internal flow field.

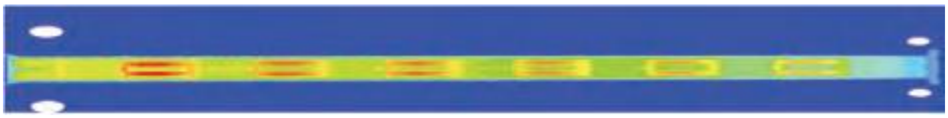

Figure 7. Temperature distribution of internal flow field.

3. Calculation results

Analysis shows that as the vertical height increases, the internal temperature of the device rises immediately, the temperature of the bottommost voltage divider module is the lowest, and the temperature of the topmost voltage divider module is the highest. In addition, as the ambient temperature increases, the internal temperature also increases. In this paper, the temperature distributions of the device are simulated and calculated at the ambient temperature of 20, 30, 40 and 50 °C respectively. The calculation results are shown in table 3 (The calculated values at the ambient temperature in cold region are not listed in table 3, and the highest temperature of the voltage divider module is numbered in the order of the topmost voltage divider module to the bottommost voltage divider module). It can be seen from table 3 that the temperature of the top single-layer voltage divider module is the highest and the lowest single-level voltage divider module is the lowest. From the vertical point of view, from the top of the single-level voltage divider module to the bottom of the single-level voltage divider module, the temperature distribution showed a decreasing trend. The temperature difference between the topmost single-layer voltage divider module and the bottommost single-layer voltage divider module is about 9 °C, and the temperature rise inside the device is about 28 K. It can also be seen from table 3 that if the device is operating in a hotter area in summer, it is necessary to check the thermal stability when the working temperature of the measuring resistor is up to about 80˚C to meet the measurement accuracy requirements of the device operation.

Table 3. Calculated values of internal temperature distribution under environment temperature/ ℃.

The number of voltage divider module	Ambient temperature			
	20	30	40	50
1	48.25	58.19	68.15	76.73
2	48.05	57.56	68.08	75.99
3	47.76	56.42	67.12	75.55
4	45.70	54.55	65.27	74.92
5	44.60	54.39	64.19	74.35
6	44.54	54.04	64.02	73.32
7	42.85	52.43	62.82	73.24
8	42.43	52.25	62.32	72.40
9	41.20	51.19	61.09	71.60
10	40.27	50.31	60.28	71.58
11	39.32	49.29	58.97	71.40
12	39.00	48.59	58.99	71.02
13	38.82	48.41	58.08	70.08

4. Verification test

In order to verify the correctness of the calculation results of the above model, further experimental verification was carried out. The verification test was carried out in the high-voltage insulation test hall of Xi'an High-voltage Electrical Apparatus Research Institute (XIHARI), and the verification test scheme is shown in figue.8 [10]. Test verification uses built-in temperature sensor, temperature sensor buried point should be under the premise of not affecting the conditions within the device can represent the key points of the internal temperature distribution device. Therefore, the test temperature sensors were buried in the voltage equalization flanges of the topmost voltage divider module, the bottommost voltage divider module and the middle voltage divider module. In addition, the device was charged with 0.35MPa insulation gas during operation. The optical connector was used to reliably transmit the internal temperature information to the outside during the test. The optical connector could also solve the problem of gas sealing during the test.

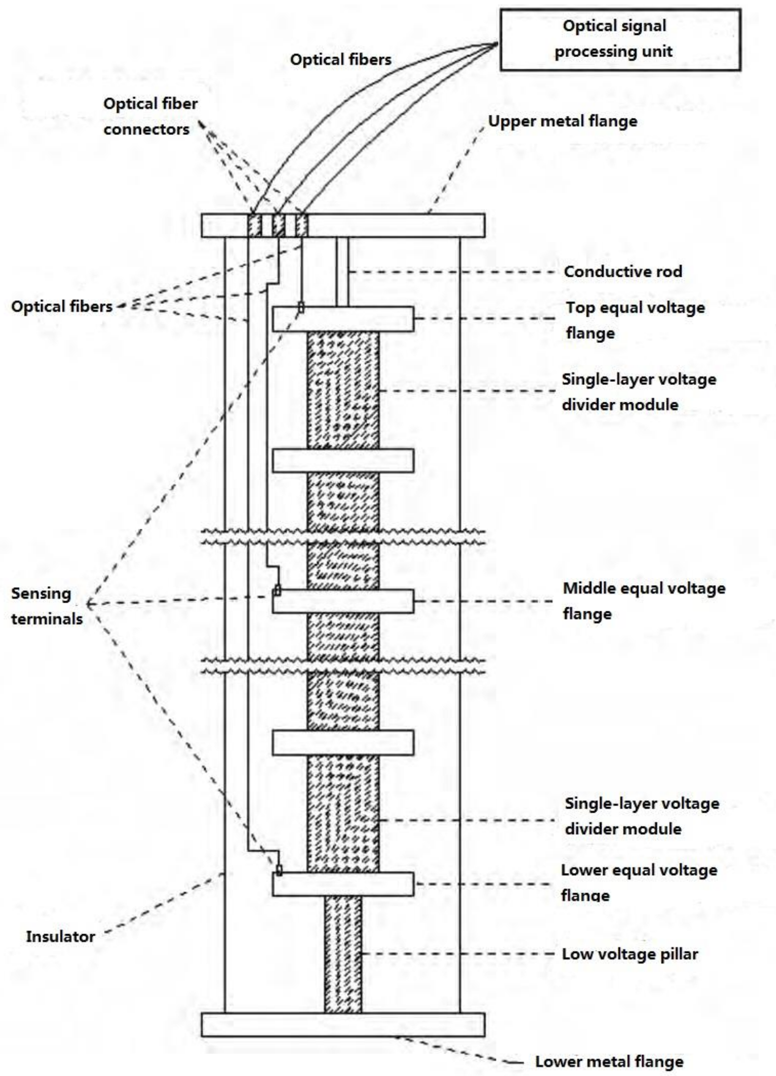

Figure 8. Implementation scheme for experiment.

The DC voltage generator used in the test can output ±1200kV DC voltage. The actual DC voltage applied was +800kV. After applying the voltage for about 12 hours at the ambient temperature, it is judged that the temperature rise within the device does not exceed ±0.5K per hour, and the heat balance is achieved within the device. The measured buried temperature data are shown in table 4, and the test site is shown in figure 9. The results in table 4 show that the maximum difference between the temperature of the topmost single-layer voltage divider module and the temperature of the bottommost single-level voltage divider module is 9.3 ℃, and the maximum temperature rise inside the device is 28.9 K, which is consistent with the model calculation.

Table 4. Temperature data of measuring points/℃.

Buried point No.1of topmost voltage divider module	Buried point No.2of topmost voltage divider module	Buried point No.3of middle voltage divider module	Buried point No.4of middle voltage divider module	Buried point No.5of bottommost voltage divider module	Buried point No.6of bottommost voltage divider module	Ambient tempera-ture
42.4	42.3	36.9	36.6	33.2	33.1	13.5

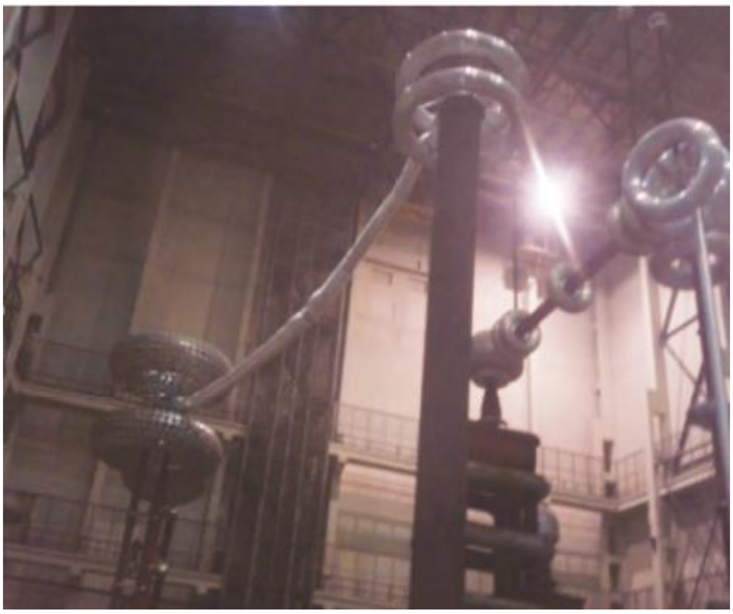

Figure 9. Test site.

5. Conclusion

By studying the internal temperature distribution of the device, we can know the internal temperature distribution of the device and further verify by the experiment that the calculation results of the flow field model established in this paper are correct. Applying the calculation model, the internal temperature distribution of the device under different ambient temperatures can be analyzed and reference can also be provided for the design. At the same time, the design of the device can be more targeted selection of resistance, capacitance devices to ensure that the device in the operating temperature range to meet the accuracy requirements and to improve the reliability of the product operation.

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