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Electrical and Mechanical Properties Research of Key Winding Materials in Dry Type Air-core Reactors at Low Temperature

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Abstract: *The low-temperature environment affects the physical properties of various materials in dry type air-core reactors, which affects the performance of the whole reactor. Therefore, when the reactor is put into operation, the insulating properties or mechanical properties of the reactor will not meet the requirements for normal operation, thus creating local defects and causing major accidents. In this paper, the insulating properties and mechanical properties of epoxy transposed wire and winding insulation are studied through AC withstand voltage tests and tensile tests under different low-temperature environments. Analysis of the test results shows that the low temperature has no significant effect on the electrical insulating properties of key materials in the reactor, but weakens the mechanical properties such as tensile strength.*

Keywords: *Low Temperature; Dry type air-core reactor; Electrical Properties; Mechanical Properties*

1. Introduction

The application of dry type air-core reactor in electric power system started from import, then the technology introduction and digestion, absorption and innovation of Chinese electrical equipment manufacturers, it has been completely localized so far. The application and quantity of this reactor in the system are also expanding with the localization of production technology. According to statistics, the proportion of dry type air-core reactors in the transmission and distribution network of 66 kV and below has exceeded 70% [1-3].

At present, although some measures have been taken for the operation of dry type air-core reactor, the effect is not obvious [4]. At the same time, due to the single means of testing, low temperature resistance test items are not clear. In order to provide a more effective judgment method and basis for the maintenance of dry type air-core reactor, it is urgent to carry out research on the operation characteristics of dry type air-core reactor and insulation testing and diagnosis technology under extremely cold operating conditions [5].

Therefore, research on the electrical and mechanical properties of key winding materials in dry type air-core reactors at low temperature needs to be carried out. Mastering the operating characteristics of reactors at low temperature is one of the important and urgent research directions to effectively avoid inter-turn short-circuit faults and accidents and to ensure the safe operation of power systems [6-8].

2. Establish a Low Temperature Resistance Test Platform

In order to study the property changes of key materials in reactors at low temperature, such as epoxy transposed wire, a key material test platform is established. The platform equipment mainly includes: industrial frequency AC power supply, partial discharge collection system, environmental chamber at low temperature, test materials, etc.

Based on the platform, the AC withstand voltage level of key materials such as epoxy transposed wire is tested to study the effect of low temperature on the insulating properties of key materials, and

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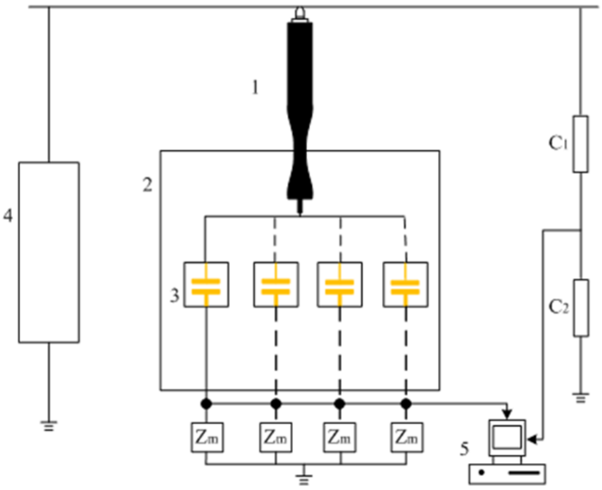
the test circuit schematic is shown in Figure 1. In addition, in order to study the effect of low temperature on the mechanical properties of materials, the performance of tensile and bending resistance of the reactor winding at low temperature is tested, and the test schematic is shown in Figure 2.



1-HV bushing; 2-Environmental chamber at low temperature; 3-Test model; 4-Power frequency AC power; 5-Partial discharge acquisition system; Zm: detection impedance C1/C2: voltage divider (1000:1)

Figure 1: Insulation Test of Reactor Winding

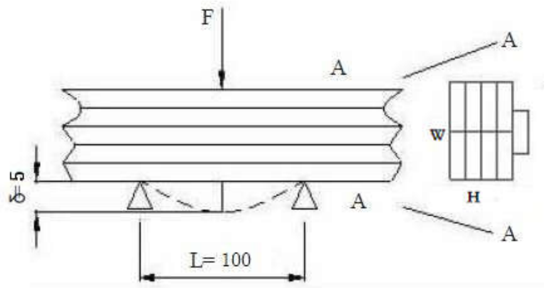


Figure 2: Mechanical Test of Reactor Winding Material

3. Research on Electrical and Mechanical Properties of Key Materials in Reactors at Low Temperature

3.1 Electrical Insulating Properties Research of Key Materials

The winding of dry type air-core reactor is usually made of multiple strands of internally transposed insulated cable, where each strand is wrapped with multiple layers of insulating film to ensure that each strand is insulated from each other, while the multiple strands are transposed and wrapped with an external insulation consisting of multiple layers of insulating film on the outside. These insulating films are the guarantee against short circuits in the reactor, the external insulation prevents inter-turn short circuit, and inter-strand insulation prevents the effects due to the contact between different strands of wire. The insulation level of these films may be affected in low-temperature environments. Therefore, in order to know about the effect of low-temperature environment on the insulation level of windings, the insulation level of insulating films is tested through withstanding voltage.

The transposed wire used is composed of 2 rows of 8 monofilament aluminum wires, each with a diameter of 2.54 mm, each covered with a 0.01 mm polyester film. The entire aluminum strand is 21.7 mm wide and 5.8 mm high, and is wrapped by two layers of polyester film with one layer of polyimide film in between, with each layer 1/3 overlapped and wrapped, each layer of polyester film is 25 μm thick and each layer of polyimide film is 25 μm thick. 25 μm-thick polyester film and polyimide film are tested at 30℃, -25℃ and -40℃ for AC withstand voltage. The wiring principle of test is shown in

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Figure 3, where X is the test object and R is the protective resistor, and the voltage data are obtained through the resistance-capacitance divider.

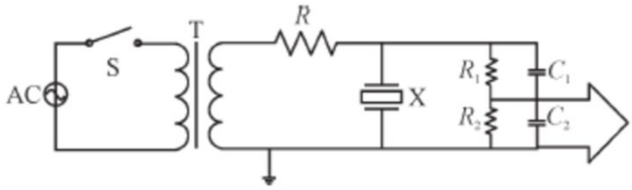

Figure 3: Wiring Schematic for Winding Insulation Film AC Withstand Voltage Test

Under three temperature conditions, withstand voltage tests at -25 ℃ and -40 ℃ are conducted in a fully enclosed low-temperature chamber, and a certain interval was ensured between each test to ensure that no water entered. Each test was performed by gradually increasing the voltage until the film breakdown, and the test data obtained are shown in Table 1 and Table 2 below.

Table 1: Pressure Resistance Level of Polyester Film at Different Temperatures

No.	30 ℃	-25 ℃	-40 ℃
1	5.2	5.2	5.1
2	4.9	5.1	4.8
3	4.8	5.1	6.3
4	5.2	5.3	6.3
5	4.6	5.5	6.5
6	5.6	5.6	6.5

Table 2: Pressure Resistance Level of Polyimide Film at Different Temperatures

No.	30 ℃	-25 ℃	-40 ℃
1	5.0	6.9	7.0
2	5.7	6.6	6.6
3	5.8	6.3	6.3
4	6.4	6.0	6.9
5	5.3	6.4	7.5
6	5.6	5.5	7.1

From the test results in Table 1 and Table 2, it can be seen that low temperature not only does not reduce the insulation level of film, but also increases the tolerance level of film at -25 ℃ compared to the room temperature, and the tolerance level of polyester film and polyimide film at -40 ℃ compared to 30 ℃ has increased about 20%. The decrease in temperature causes the insulation level of film to rise, this phenomenon shows that insulating films do not have defects in insulation level at low temperature.

3.2 Research on Mechanical Properties of Key Materials

Hollow conductors of dry reactor are made of aluminum, with polyester film wrapped on the surface of each conductor and as the main material for inter-strand insulation. In order to ensure the external insulation and isolation from the external environment, each envelope is made of multiple layers of branches in parallel, and the outer surface is wrapped with the glass fiber/epoxy resin composite. Due to the difference in the coefficient of thermal expansion between the winding and the encapsulated insulation material, the coefficient of thermal expansion of aluminum wire is 2.3×10^{-5}/K, while that of the epoxy resin/glass fiber composite is 2.7×10^{-6}/K. When the temperature changes, the firmly bonded winding and the epoxy glass wire impregnated with epoxy resin will contract differently, and create stress on the connection between the two.

In addition, dry type air-core reactors are susceptible to mechanical stresses such as tension-compression stresses, vibration and extension under the effect of alternating magnetic fields. The accumulation of these stresses may cause deformation of the encapsulated structure, which may cause the insulation material to tear or pull off in severe cases. If the tensile/compressive strength of conductor and epoxy glass wire material cannot restrain the stresses due to thermal expansion and contraction at low temperatures and the electric stresses generated during operation, wire and insulation materials will occur deformation, which will lead to cracking in serious cases. Therefore, whether there

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is deformation and cracking between the conductor and insulation material is determined by both the ultimate stress that the material can withstand and the actual stress that withstands in operation.

For the research of tolerable ultimate stress of winding and encapsulation, in order to investigate the effect of temperature on the withstand able ultimate stress between winding and epoxy resin, the bonded epoxy resin and winding are divided into small pieces of epoxy transposed wire of 10 cm × 10 cm, and then tensile tests are performed on them. The tests are performed at room temperature of 27℃, -25℃ and -40℃. The epoxy transposed wires are stretched, and the load is gradually increased until the transposed wires are completely separated from the epoxy resin. The tests are repeated seven times in each case, and the test data obtained are shown in Table 3 below.

Table 3: Tensile Test of Reactor Coil Material

Sampie	27 ℃ stress (kPa)	-25 ℃ stress (kPa)	-40 ℃ stress (kPa)
1	340.3	322.8	311.8
2	349.5	259.4	413.9
3	339.4	255.7	264.0
4	392.7	372.5	329.3
5	341.2	417.5	248.3
6	342.1	428.6	249.2
7	456.2	262.1	240

As can be seen, the low-temperature environment has a large effect on the maximum tolerable stress of the epoxy transposed wire, and the tolerable stress decreases significantly as the temperature decreases. The average stress is 365.9 kPa at room temperature of 27℃, 331.2 kPa at -25℃, with a 10% decrease compared to the room temperature, and only 293.8 kPa at -40℃, with a 20% decrease compared to the room temperature.

This phenomenon may be caused by the different degree of shrinkage of the winding and the epoxy resin at low temperatures and the change in the nature of the adhesive at low temperatures. The decrease in the maximum withstand stress indicates that the low-temperature environment causes a significant decrease in the bonding properties of the epoxy transposed wire compared to room temperature, making the bonding state between the two more fragile. In the process of reactor input, a transient electromotive force is generated, and the uneven heating of the wire and the epoxy also generates a stress. Since the maximum stress that the bonding between the epoxy and the winding can withstand decreases at low temperature, the electromotive force acting on the epoxy transposed wire makes it easier to create cracks between the epoxy and the winding, thus damaging the insulation.

4. Conclusion

In this paper, based on the reactor low-temperature test platform, the mechanical properties of epoxy transposed wire at low temperature and the insulating properties of windings at low temperature are studied. Analysis of the test results shows that low temperature has no significant effect on the electrical insulating properties of key materials in the reactor, but weakens the mechanical properties such as tensile strength.

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