Operation improvement measures of dry type air-core reactor in severe cold environment

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Abstract. In severe cold environment, the surface of dry type air-core reactor would easily be cracked, once natural contamination accumulated on the cracks, surface flashover would have more possibility to happen, leading to more serious reactor faults. The most commonly used methods to avoid reactor surface discharge includes RTV coating and surface decontamination using water-based cleaning agent, yet the effects of these methods, as well as possible impact on reactor performance have not been fully studied. In this paper, RTV coating and decontamination tests were carried out to evaluate the effect of the methods, also the impact of these two methods on reactor electrical performance were analyzed. The research result showed that: (1) Water-based cleaning agent was effective in removing contamination on insulation paint surface, but less effective in removing contamination on RTV coated surface; However, the water-based cleaning agent would cause damping between the winding strands, and damping recovery degree was not easy to control. Therefore, water-based cleaning agent was not suitable to solve surface flashover problem of dry type air-core reactors. (2) The overall coating for reactor surface and air duct could be realized by special spraying equipment. The adhesion test showed that RTV was of good covering and adhesion performance, and had little impact on reactor temperature rise, indicating that RTV could be an effective measure to improve operation quality of dry type air-core reactor in extreme cold environment.

1. Introduction
In China, dry type air-core reactors were widely used in 10~66 kV power grid for its excellent compensation performance and low price. However, with the large-scale application of dry type air-core reactors, faults occurred frequently, especially in extreme cold areas of northeast China. According to factory repair statistics by a main reactor manufacture, 82% of the 20000 KVA/ 66 kV shunt reactor faults in China’s power grid happened in northeast cold area. Moreover, those failures had similar characteristics that surface flashover were found, mostly concentrated on contaminated and cracked surface of reactor air duct, as shown in figure 1.
According to the fault characteristics and previous research, it was commonly believed that natural contamination, moisture and cracks on the reactor surface were the main causes of surface discharge faults[1-5]. Thus, in order to improve operation reliability of dry type air-core reactor and avoid the impact of natural contamination and cracks, the effect of improvement measures like RTV coating and water-based cleaning, as well as possible impact on reactor electrical and thermal performance were analyzed by tests.

2. Water-based cleaning method

The agents used for reactor surface cleaning included water-based, solvent-based, and special cleaning agents[6], among which the solvent-based and special cleaning agents were expensive and few used in engineering. The water-based agents were widely used due to its high cost effective and environmental-friendly performance.

2.1 Effect of surface cleaning method

The tests were carried out to study effect of water-based agent on reactor surface cleaning. Two surface polluted reactor samples were flushed by high-pressure spray machine using different concentrations of water-based cleaning agents. The pollution information of two reactor samples and cleaning agent proportions were shown in table 1 and table 2.

| Table 1. Reactor sample contamination information |
| Sample number | Characteristics |
|----------------|------------------|
| 1#             | The reactor surface was coated with insulation paint, which was placed outdoor for 5 years, with heavy pollution accumulation. |
| 2#             | The reactor surface was coated with RTV, which was placed in packing box for 3 years, with light pollution accumulation. |

| Table 2. The water-based cleaning solution concentrations |
|----------------------------------------------------------|
| Test number | 1# | 2# | 3# |
| Agent proportion | 50% | 33% | 16% |
| Water proportion  | 50% | 67% | 84% |

The cleaning process were conducted using spray of 5 atmospheric pressures, and a flow rate of 2L/ min. The decontamination effect was illustrated in table 3. According to the test result, although dry type air-core reactor were of poor surface flatness, and was considered to be detrimental to remove surface
pollution, yet it was found that for reactor sample 1# which was coated with insulation paint, even using the least proportion of cleaning agent, the cleaning effect was good. However, for reactor sample 2# which was coated with RTV, the cleaning effect were all poor for each concentration of detergent solution. The poor cleaning effect was considered to be related to hydrophobicity characteristic of RTV material.

Table 3. Cleaning effect of the samples

|          | Test 1# | Test2# | Test3# |
|----------|---------|--------|--------|
| Sample 1# | good    | good   | good   |
| Sample 2# | poor    | poor   | poor   |

2.2 Influence of surface cleaning method on electrical performance of reactor

Since the main component of water-based cleaning fluid was water, the cleaning method would inevitably cause damping to the reactor. Thus, it is necessary to analyze possible influence on reactor’s electrical performance.

2.2.1 Influence on insulation between strands. After cleaning test, the first and second layer of reactor sample 1#, as well as second and third layer of reactor sample 2# were taken out. Then the insulation resistance tests were carried out for the winding strands. The test results were listed in table 4, for each winding sample, insulation resistance before cleaning test were also illustrated.

Table 4. Insulation resistance before and after cleaning (MΩ)

| Time   | Winding sample of 1# reactor | Winding sample of 2# reactor |
|--------|-----------------------------|-----------------------------|
|        | Layer 1 | Layer2 | Layer 2 | Layer 3 |
| Before cleaning | ∞     | ∞     | ∞       | ∞       |
| 24h    | 1500   | 1000  | 560     | 68      |
| 48h    | 1800   | 1650  | ∞       | 523     |
| After cleaning | 72h   | ∞     | ∞       | 1000    |
| 96h    | ∞      | ∞     | ∞       | 1400    |
| 120h   | ∞      | ∞     | ∞       | ∞       |

The test results indicated that water-based cleaning agent could greatly reduce the insulation performance between strands of reactor windings, although with extension of placing time, the insulation resistance could be recovered, yet the recovery time showed a random characteristic. Therefore, it is hard to make sure of the recovery degree and natural recovery time of winding insulation after cleaning using water-based cleaning agent.

2.2.2 Influence on reactor loss. The reactor loss tests were conducted for both 2 reactor samples before and after cleaning, using high precision power analyzer WT3000. The after-cleaning test were done 24 hours after cleaning. The loss test results were shown in Table 5. According to the result, it was found that for reactor sample 2#, loss tested 24 hours after cleaning were still 17.6% higher than that before cleaning. The high loss was considered to be related to unrecovered damping.
Table 5. Loss test result before and 24 hours after cleaning

| Reactor sample | Before cleaning | After cleaning | Change percentage |
|----------------|-----------------|----------------|-------------------|
| 1#             | 2.389           | 2.293          | -4.02%            |
| 2#             | 4.655           | 5.476          | +17.6%            |

2.2.3 Influence on inter-turn insulation performance. Inter-turn over-voltage tests were conducted before and after cleaning to study possible impact on inter-turn insulation performance. The test was done based on the standard GB/T 1094.6, the test circuit was shown in figure 2. As the test result, the surge voltage waveforms before and 24 hours after cleaning for reactor sample 1# were shown in figure 3, while the waveforms for reactor sample 2# were shown in figure 4. It could be seen from the waveforms that the full voltage and half voltage oscillation frequencies were the same, indicating no inter-turn insulation deterioration were occurred for both of the samples.

![Figure 2. Inter-turn over-voltage tests circuit](image)

![Figure 3. Inter-turn test waveform of reactor sample 1#](image)

![Figure 4. Inter-turn test waveform of reactor sample 2#](image)
3. RTV coating method

The discharge faults in cold Northeast China were found to be typical pollution flashover. According to previous research, RTV materials were proved to be effective in avoiding pollution and wet flashover[7-10]. Therefore, the effect of RTV coating on reactor operation improvement in extreme cold environment, also possible influence on reactor performance were discussed in the following.

3.1 Effect of RTV coating method

In order to prevent surface discharge of reactor, the surface of air duct and bracing struts should all be covered. During investigation and onsite test, it was found that since the air duct of reactor were narrow and deep, the conventional RTV spraying method could only achieve surface coating on the ends of reactors, the coating for internal air duct and contact angle between encapsulation layer and bracing strut were quite hard. Therefore, spraying equipment with special nozzle structure was recommend to use. The coating effect of RTV coating using conventional and special nozzle structured equipment were illustrated in figure 5.

Conventional spraying Special equipment spraying

Figure 5. RTV coating effect

3.2 Influence of RTV coating on reactor performance

The primary requirement for RTV coating to take effect was to firmly adhere to reactor surface. Once coatings fell off, not only couldn’t it prevent surface discharge, but also the air duct would be blocked due to the falling material fragment, resulting in partial temperature rise and insulation aging, which would be more likely to cause serious failure.

3.2.1 RTV coating adhesion test. The surface of the air duct which has been commissioned would usually be covered with pollution that could not be easily removed, which could probably affect the adhesion performance of RTV coating. The pieces of surface material of a commissioned reactor were obtained as polluted sample, while standard epoxy plate was used to simulate absolute new and clean air duct surface as control group samples. The adhesion performance of the two groups of samples were tested in the following.

The standard epoxy plate was cleaned by alcohol and dried out, then coated with RTV, then the adhesion performance of clean sample was tested by scratch method. The polluted test sample were taken from commissioned reactor encapsulations, with size of 100×80mm, which was the same size with the standard epoxy plate. The dust on polluted sample were blown off and RTV was covered, then the adhesion performance of polluted sample was tested using cross cut method. The adhesion test results of standard plate and polluted samples were illustrated in figure 6, it could be seen that both on clean and light polluted surface, RTV coating had good adhesion performance.
3.2.2 Influence of temperature change on RTV Adhesion Performance. The temperature changes due to putting into operation or cutting off, as well as day and night temperature difference would cause temperature gradient in reactors. For those reactors operated in extreme cold area, the temperature change would be more intensive and might have impact on reactor performance as well as RTV coating stability. In order to study RTV adhesion stability under temperature change condition, the temperature variation cycle tests were carried out, the test conditions and results were illustrated in table 6. The temperature cycle test showed that RTV coatings had good adhesion competence under intensive temperature change condition, indicating that ambient temperature change had little effect on RTV adhesion performance.

Table 6. Temperature variation cycle tests result

| Test period | Low temperature / time | High temperature / time | Cycle times | Adhesion       |
|-------------|------------------------|-------------------------|-------------|----------------|
| 1           | -10°C /3h              | 110°C /3h               | 3           | 0Grade (excellent) |
| 2           | -10°C /3h              | 120°C /3h               | 3           | 0Grade (excellent) |
| 3           | -10°C /3h              | 140°C /3h               | 10          | 0Grade (excellent) |

3.2.3 Influence of RTV coating on temperature rise performance of reactor. After the reactor air duct were coated with RTV, the thickness of surface insulation was increased, which could possibly change the heat transfer coefficient of reactor, and affect the heat dissipation performance of the reactor. In order to study the influence on heat dissipation after RTV coating, temperature rise tests were conducted for reactors before and after coating. The test was conducted based on the standard GB/T 1094.2, and test circuit was shown in figure 7.

Figure 6. Adhesion performance of RTV on reactor surface

Figure 7. Temperature rise test circuit
Table 7. Temperature rise before and after RTV coating

| Layer | Before coating | After coating |
|-------|---------------|--------------|
| 1     | 40.9          | 38           |
| 2     | 54            | 44.7         |
| 3     | 55            | 44.4         |
| 4     | 46            | 39.9         |
| 5     | 57.1          | 48.6         |
| 6     | 52.7          | 47.4         |
| 7     | 51.9          | 49.6         |
| 8     | 47            | 52.4         |
| 9     | 42.7          | 37.5         |
| Average | 42.5        | 39.3         |
| Hotspot | 57.1        | 52.4         |

As shown in table 7, the temperature rise test results indicated that after coated with RTV, the average and hot spot temperature rise of reactor decreased slightly, which might be related to the improvement of air duct surface cleanliness, the clean surface would be beneficial to air flow and thus improving the heat dissipation capacity. Yet, those heat dissipation improvement effect after RTV coating were not that obvious.

4. Conclusion
According to the study, the main causes of dry type air-core reactor faults in extreme cold environment were surface cracking and pollution, contamination cleaning and RTV coating were supposed to be effective measures to solve the problem. By analyzing effect and possible impact of these two methods, several conclusions were drawn as follows:

- The water-based cleaning agent could remove pollution on insulating paint surface, but was of poor effect on RTV coated surface. Though using cleaning method could not lead to inter-turn insulation faults, the damping caused by water was proved to decrease insulation resistance between strands, meanwhile, damping recovery condition could not be precisely controlled. Therefore, the dry type air-core reactor should not be cleaned by water-based detergent. The auxiliary improvement measures like anti snow and bird damage devices could be considered to install on site to tackle with pollution problems.

- The RTV material showed good adhesion performance on reactor surface, with low influence on temperature rise of the reactor. In addition, the RTV coating could restrain cracks and electric field distortion on the reactor surface, which was useful to prevent surface flashover. Thus, RTV coating on reactor air duct surface were proved to be an effective measure to improve operation reliability of dry type air-core reactors.

- After RTV coating, the moisture-proof and pollution-proof ability would be greatly improved, which was conducive to the safe operation of the reactors. However, the coating fragment drop caused by uneven coating and natural aging could possibly lead to air duct blocking, so it was suggested that operation staff should check coating condition at regular interval to guarantee the function of RTV.

5. Reference
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