Current Carrying Characteristics of Energy-Saving and Loss-Reducing Conductor Joint

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Abstract. The loss of submarine cable is an important problem in the process of design and manufacture. In this paper, the technology of the energy-saving and loss reducing conductor joint was introduced. The current carrying capacity test of energy-saving and loss-reducing conductor was carried out. At the same time, the same current was applied to the common stranded conductor and the energy-saving loss-reducing conductor, and the heat loss of the conductor under the same test environment was compared. The experimental results showed that at the connection of outgoing terminal and connecting pipe, the contact resistance of the layer insulated conductor was greatly reduced after depainting treatment. Meanwhile, the temperature of thermocouple after paint removal was obviously reduced in the current carrying capacity test. Compared with bare copper single wire stranded conductor, laminated enamelled insulated stranded conductor could reduce the power loss.

1. Introduction

In recent years, submarine cable transmission project is an important part of cross sea area networking project construction\cite{1-3}. In order to improve the current carrying capacity of submarine power cables, it is necessary to reduce the AC resistance of cable conductors\cite{4}. With the development of modern cable in the direction of high voltage and high current, more and more cables are adopted large cross section\cite{5}. The skin effect and proximity effect will greatly increase the AC resistance, which results in a large operating loss of large cross-section submarine cable. Therefore, it is of great economic significance to study the technology of large section energy-saving and loss-reducing conductor.

In recent years, scholars at home and abroad have carried out a lot of researches on energy-saving and loss-reduction technology of submarine cable. Li\cite{6} used the kauer trapezoid network to establish the calculation model of submarine cable loss, and obtained the loss of submarine cable medium and metal armor through simulation. He analyzed the loss of different armored submarine cables in different laying environments in combination with the second loop Hainan networking project. Zhang\cite{7} used classic thermal path method, COMSOL software simulation and thermal cycle test to carry out in-depth research on the current carrying capacity and electric heating characteristics of submarine cables. He analyzed the loss of lead cladding and armor layer of submarine cables. It provided a theoretical basis for the development of submarine cable energy saving and loss reduction technology. From the current research progress, the current researches at home and abroad focus on reducing the
loss of submarine cable media, lead cladding, armor and so on. In addition, most of the submarine cable conductors are circular compact conductors. However, the manufacturing process of the joint of layered insulating conductor is more complicated. At present, the AC resistance and loss of the connector are rarely reported.

In this paper, the effects of different crimping processes on conductor temperature rise and current carrying characteristics were studied. The traditional layered conductor joint and the spontaneous development of energy-saving and loss-reducing conductor joint were used. Thus, the feasibility of the manufacturing process of energy-saving and loss-reducing conductor joint with layered insulation was verified.

2. Test of current carrying characteristics of conductors

2.1. Sample preparation

The laminated insulated conductor used in this test was composed of 1 + 6 central conductors. The first layer outside the center layer was 12 enameled wire layers. The second layer was a layer of 17 copper wires. The third layer was 22 enameled wire layers. The fourth layer was 27 copper wires. The fifth layer was 32 enameled wire layers. The sixth layer was a layer of 36 copper wires. There were 153 copper conductor single wires and enameled wires in total. These seven layers were tightly twisted. The structure diagram was shown in Figure 1.

![Figure 1. The diagram layered insulating conductor](image)

In the process of conductor paint removal, compact circular conductor should be layered. In the current scheme, each layer of conductor must be broken off to facilitate the recovery of conductor after paint removal. The structure diagram of the conductor was shown in Figure 2. The conductor should be 20 mm shorter from outside to inside in turn. In this test, the layered insulation conductors of group A were not treated. The joints of group B were made by means of current sharing crimping conductor joints. In both groups, terminals 4 were not painted and terminals 7 were painted. In group B of this test, two paint removal methods, fire baking and paint remover, were used to remove the paint of layered insulating conductor.

![Figure 2. The diagram of conductor fixing after paint removal](image)

2.2. Test loop and equipment

The test circuit of this test is shown in Figure 3. The point 1 to point 11 are as follows: ①copper single wire conductor crimping terminal; ②copper single wire conductor; ③copper single wire conductor crimping terminal; ④laminated insulated conductor without painted crimping terminal; ⑤laminated insulated conductor; ⑥laminated insulated conductor; ⑦laminated insulated conductor after burning
of the paint crimping terminal; ⑧ laminated insulated conductor burning off the paint crimping connecting pipe; ⑨ laminated insulated conductor paint remover paint crimping connecting pipe; ⑩ short copper bar; ⑪ long copper bar. T₁ means temper temperature of ①. In the test, the auxiliary temperature measuring point (A, B, C and D) and other temperature measuring points measured temperature synchronously. It helped to analyse the influence of temperature rise on the temperature distribution of layered insulating conductor. In the test, the large current test transformer (through transformer), voltage regulator, contact resistance tester, thermal cycle control system, hydraulic clamp and thermocouple temperature measuring device were used.

2.3. Temperature rise test
In the temperature rise test, the output of the voltage regulator was adjusted first. And the current was applied through the core transformer in the first 6 hours, the stable amplitude of applied current was 1.2I₀ (1524A). In the next 2 hours, the current dropped to 1.1I₀ (1397A). During the test, the temperature, current value, ambient temperature and humidity of each temperature measuring point were recorded every 0.5 hours.

3. Experimental results
The curves of temperature change with time at the temperature measuring points of the two groups were shown in Figure 4 and Figure 5. The curve of temperature change with time at auxiliary temperature measuring point was shown in Figure 6. It can be seen from the comparison of T₈ curves and T₉ curves in Figure 4 and Figure 5 that the resistance of the connecting tube after paint removal tended to be lower. The reduction ratio was as high as 30%. It showed that paint removal could effectively reduce the contact resistance at the connecting pipe. In group B test, T₉ is lower than T₂, and T₈ is slightly higher than T₂. It could be seen that the manufacturing process of the conductor joint proposed in this paper could make the resistance of the layered insulated conductor joint close to the circular compact conductor joint. In group B test, the T₈ was lower than T₆. The joint 8 was painted by fire and the joint 9 was painted by paint remover. From the test results, the effect of paint removal by fire was better, but the operation of paint removal by fire was more complex. The good results could also be obtained by using paint remover. Therefore, two paint removal methods could be used. It can be seen from the comparison of curve T₅ and T₆ in Figure 4 and Figure 5 that the temperature of connecting pipe after paint removal was greatly reduced. The temperature of enameled wire conductor also decreased, and it was close to that of copper single wire conductor. It showed that the temperature rise of enameled wire conductor was affected by the connecting pipe.

In group B, T₅ was about 11 °C higher than T₆. It can be seen from the fact that ④ connected with ⑤ and the T₆ is 11.5 °C higher than T₅, because of the temperature rise effect of ④ without paint removal. In both groups, T₆ was less than T₂. ⑥ is a conductor with layered insulation and its temperature was lower than that of copper single wire conductor. From the data of group A and group B, we could see that the temperature rise and stable temperature of group A were higher than that of
group B because the connecting pipe was not painted. And the temperature measuring points 5 and 6 were close to the connecting pipe. Therefore, the temperature of group A was higher.

![Figure 4. The test results of group A](image)

![Figure 5. The test results of group B](image)

![Figure 6. The temperature change of auxiliary temperature measurement circuit](image)

4. **Conclusions**
In this paper, the connection technology of energy-saving and loss-reducing conductor joint was introduced. In order to analyze the improvement effect of energy-saving and loss-reducing conductor,
the current carrying capacity test was carried out on the common stranded conductor and the energy-saving and loss-reducing conductor. The main contents of this paper are as follows:

①At the connection of outgoing terminal and connecting pipe, the contact resistance of the layer insulated conductor was greatly reduced after depainting treatment. At the same time, the temperature of the connecting pipe decreased from 129 ℃ to 73 ℃ during the current carrying test.

②The joint resistance could be effectively controlled in two ways: fire paint removal and paint remover paint removal. Compared with bare copper single wire stranded conductor, laminated enamelled insulated stranded conductor could reduce the power loss.

③By technology of layered insulated conductor joint proposed in this paper, the AC resistance of the joint could be effectively controlled. This will lay a foundation for the practical application of layered insulation of large cross-section submarine cable.

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