Experimental Study of Hybrid Deicing System

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Abstract. The hybrid deicing system combines the traditional electrothermal deicing system with the electro impulse deicing system. Firstly, the prototype design of the ice wind tunnel hybrid deicing system is carried out, and the electrothermal deicing system and the electro impulse deicing system are integrated in the airfoil model. Then, through the laboratory plate deicing experiment to study the deicing effect of different heating and excitation combinations, explore the work control law of the hybrid deicing system, and finally verify the effect of the hybrid deicing system through the ice wind tunnel test. The plate panel test found that with the increase of the surface temperature of the skin, there is a minimum binding force between the ice and the skin. In the ice wind tunnel deicing experiment, the prototype of the hybrid deicing system shows a good deicing effect with less energy consumption.

1. Introduction

The traditional electrothermal deicing technology is a widely used aircraft anti-icing technology. It has high efficiency and simple structure, but it has the disadvantages of high energy consumption and easy formation of runback ice[1]. The large energy consumption of electrothermal deicing directly affects the life time of the aircraft[2]. For small, medium-sized aircraft and drones with insufficient energy, electrothermal deicing energy consumption will become unacceptable. Runback ice and ice ridge will seriously affect aircraft flight safety[3, 4].

The electro impulse deicing technology was first proposed by Soviet scientists[5]. The principle is to install a pulse coil under the metal skin and use the instantaneous discharge technique to form an electromagnetic eddy current field on the metal skin, thus generating a transient electromagnetic force, which leads to electromagnetic force. The skin quickly vibrates and deforms and the ice layer breakup and fall off, and finally removes the ice under the action of aerodynamic forces and inertial forces. The electro impulse deicing technology has the advantages of low energy consumption, simple installation and easy maintenance, and not easy to generate runback ice. The United States[6], Europe[7] and other countries[8] have conducted a lot of research but have not yet been commercialized[9]. Because the vibration of excessive frequency is easy to cause skin fatigue damage. Secondly, the strong magnetic interference generated by the electro impulse discharge is easy to cause interference to other electronic equipment of the aircraft. Currently only Russia applies the deicing technology on aircraft. The electro impulse deicing technology belongs to the mechanical deicing technology.

The hybrid deicing combines the electrothermal deicing technology with the electro impulse deicing technology, and uses the electric heating system to reduce the bonding force of the ice layer-skin surface, and then uses the electro impulse to destroy the ice layer to achieve the deicing effect,
which reduces the energy consumption of electrothermal deicing also reduces the damage of the skin by electro impulse deicing. In 1997, the United States Kamel AL-Khalil carried out experimental research in IRT, which showed that the method is suitable for de-icing of surpercooled large droplets. The electro impulse de-icing system can prevent the water generated by the heating of the leading edge heating belt from generating runback ice[10]. And the The hybrid deicing has the advantage of energy saving[11].

2. Plate deicing test

2.1. Plate deicing test model

Figure 1 shows a schematic diagram of a conventional electrothermal deicing system on a section of a wing, consisting of three pieces of heating belts. Design a hybrid deicing system based on the traditional electrothermal deicing system. As shown in Figure 2, reduce the area of the upper and lower airfoil heating belts to allow sufficient space for the impulse to operate. The two circular positions in the figure are the positions of the impulse on the surface of the skin.

![Figure 1. The schematic diagram of conventional electrothermal deicing system](image1)

![Figure 2. The schematic diagram of hybrid deicing system](image2)

The test plate is shown in the figure 3. The test plate material is made of aluminum alloy. The size of the plate is 600mm×420mm×2mm (length, width and thickness), and the back of the aluminum plate is close to 540mm×370mm×3mm (length, width and thickness). The heating film’s power is 480W, and the model is equipped with an electro impulse system in the area of the unheated film in the middle of two sides, and its structural layout is as shown in the following figure.
2.2. Test conditions
The plate deicing test was completed in the open freezer, and the icing conditions were basically the same. The test conditions are shown in Table 1. In each test, water was sprayed layer by layer on the surface of the plate before deicing began to produce about 15 cm thick glaze ice.

Table 1. Test conditions of plate deicing tests

| Temperature (°C) | Heating power (W) | Deicing time (s) | Number of Impulse |
|------------------|-------------------|------------------|-------------------|
| -20              | 480               | ≈300             | 6                 |

2.3. Test results
As shown in Figure 4, the results of the electro impulse deicing test show that the ice layer has a large area crack due to the surface deformation of the plate plate, but because the ice layer and the plate surface are firmly bonded, there is no large area of ice on the plate surface falling off.

As shown in Figure 5, the result of the hybrid deicing test is that after heating for 280 s with 480 W heating power and then impulse for 6 times, most of the ice layer also has large-area cracks due to surface deformation of the plate plate, and the surface temperature rises with the electric heating plate. The adhesion between the layer and the surface of the plate is reduced, and a large area of ice is detached.
3. Icing wind tunnel deicing test

3.1. Test model
Figure 6 shows the structural assembly drawing of the ice wind tunnel test model. The hybrid deicing system is arranged in the front wing section. The electro impulse system is arranged in the model fixed on the beam. Figure 7 shows the Installation position of heating film, and the heating system is arranged on the front wing surface.

3.2. Test procedure
The icing wind tunnel deicing tests was carried out in the FL-61of AVICARI. The size of the FL-61 icing test section was $0.6 \times 0.6m$. 
Firstly, the hybrid deicing system is tested on the ground to confirm that the heating system and the electro impulse system are working properly, and the model is insulated. Then carry out the hybrid deicing test in the ice wind tunnel.

Based on the experience of the previous plate-plate deicing test, firstly, a certain thickness of ice is formed on the surface of the wing and then the heating system is turned on. After heating for a period of time, the electro impulse system is turned on.

3.3. Test conditions
The icing conditions of icing wind tunnel deicing tests are based on the continuous maximum icing conditions of CCAR25-R4 Appendix C. The specific icing conditions are shown in Table 2.

| Volocity (m/s) | MVD(μm) | LWC (g/m3) | Temperature(℃) |
|----------------|----------|------------|----------------|
| 40             | 20       | 1.4        | -9.4           |

3.4. Test results
Figure 8 shows the results of the deicing experiment of the ice wind tunnel of the principle sample. It can be seen from the figure that the results of the deicing of the plate plate are basically the same. The heating system heating reduces the combination of the ice and the skin of the leading edge. After the electro impulse system act, a large area of ice layer on the front edge falls off. However, due to the large curvature of the leading edge of the airfoil, the impulse effect of the electro impulse system at different positions is different, so there is still some residual ice on the upper and lower airfoil.

4. Conclusion
The electrothermal deicing system and the electro impulse deicing system are integrated to form a hybrid deicing system, and the plate deicing test and the ice wind tunnel deicing test are carried out.

(1) The plate deicing test explores the hybrid deicing method. As the surface temperature of the plate plate rises, the bonding force between the ice layer and the plate plate decreases, and the ice layer is more likely to fall off under the action of the electro impulse system.
(2) Icing wind tunnel de icing test verifies the principle of the hybrid deicing system. For the large-area icing of the leading edge, the composite de-icing method of heating and then impulse can cause the ice layer to fall off in a large area, but Due to the large curvature of the leading edge, the impulse effect of the impulse force is uneven, and the ice in the vicinity of the icing limit is not easily shaken, and residual ice is formed.

(3) According to the results of the ice wind tunnel test, the layout and design of electrothermal system and the electro impulse system in the test model are to be optimized, so that the impulse force will be more evenly activated, and the deicing effect of the hybrid deicing system will be improved.

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