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# Icing and Anti-Icing of Railway Contact Wires

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## 1. Introduction

The icing of overhead electrical transmission lines, or railway contact wires, may cause a series of problems such as overloading, non-uniform icing, and wire galloping. In countries with cold climates such as the U.S.A., Canada, China, glaze and rime deposits on power transmission lines and electrical railway contact wires are crucial problems for engineers and scientists working in these fields. Power cables and towers have been damaged or destroyed on numerous occasions due to the added burden of the ice or an increase in aerodynamic interaction leading to unacceptable movement such as galloping. The research on the mechanisms of icing and anti-icing is both a basis of transmission line design and a new objective of the environmental thermophysics study.

Atmospheric icing may have a great impact on the overall design and safe running of power transmission lines or railway contact wires. For engineers attempting to determine ice loads in a specific area, knowledge of historical ice events and ice type for that area would be extremely important. However, there is no systematic ice accretion database that can be used to help engineers. The prolonged period of ice storm of Central and Southern China in 2008 caused extensive damage to the electrical installations and electrification railways. As a result, the transmission provider of the state has deployed substantial efforts to mitigate the effects of future ice storms.

This chapter mainly introduces the icing of railway contact wires and corresponding anti-icing technologies and deals with the following four aspects: (1) the hazards of the icing of railway contact wires and significances of this research; (2) the characteristics of the icing of railway contact wires and affecting factors of the icing; (3) experimental research into the icing and anti-icing of railway contact wires; (4) expert system of the icing and ice melting of railway contact wires. Through the above introduction, the paper aims to make researchers, engineers and managers who are interested in this field have a comprehensive understanding of the causes, hazards and contributing factors of the icing of railway contact wires, to let them have a basic knowledge of icing and ice melting and the current technologies of anti-icing and ice removal and finally to provide readers with an expert system that can anti-ice and melt ice.

### 1.1 Background of research into icing of railway contact wires

Large, heavy ice accretions may form on objects exposed to freezing rain. These can damage or destroy structures and cause great economic and social hardship.

The United States, Canada, France, Russia, Japan, Korea, etc. are frequently attacked by icing in the world. In February 1994, large areas of southeastern United States had suffered heavy ice accidents, resulting in the direct economic losses of 30 billion. In 1998 and 2003, the United States and Canada had a large-area wire icing accident once again, causing greater economic losses.

In China, Hunan, Hubei, Jiangxi, Yunnan, Guizhou, Sichuan, etc. are areas where heavy icing is very common. Since Hunan and Hubei had an icing accident in 1954, Central China Power Grid experienced the worst ice disaster in the history in February 2005. Thousands of miles of transmission lines were covered with ice, and Hunan Power Grid became a "Severely Afflicted Area ". The maximum thickness of ice covered on wires is up to 70 ~ 80mm, which is extremely rare. This heavy icing resulted in the collapse of 21 towers with 500KV transmission line, causing the electric power of Three Gorges not to be sent to Guangdong, which incurred heavy economic losses. In January 2008, the ice storm which lasted for half a month caused unprecedented damage to transmission lines, communication lines and electric railways in 10 provinces of Southern China. The power supply in Hunan, Hubei, Guizhou, Guangxi and other provinces were seriously affected. There have been no power and water supply for two weeks in Chenzhou. The Beijing-Guangzhou electrification railway was cut off by icing in Chenzhou, Hunan province and traffic was severely interrupted.

Therefore, the researches of icing mechanism and solutions to the problem have good engineering application prospects, and significant economic and social benefits.

### 1.2 Research progress about the railway contact wire icing

Few papers about the research of railway contact wire icing can be found. In the limited literature, there are more ones about the study of the roof insulator flash by icing, and fewer ones about the analysis of the cases and countermeasures of the contact wire icing. Generally speaking, they simply make a description of the phenomena or a simple analysis of the causes of icing. Very little literature is concerned with the theory of contact wire icing forecast models and mechanism analysis.

The research of contact wire icing has not been paid enough attention to, perhaps due to the following reasons:

First, the development of electrification railways is relatively late and large-scale construction has just been started. The contact wire has not been extended to the areas where ice accretion are apt to happen (for China, such areas mainly refers to mountains, lakes and other similar places in Hunan, Hubei, Jiangxi, Guizhou, Sichuan, Yunnan, Anhui, etc.);

Second, because of global warming, disastrous icing events have not happened in the freezing rain areas for the last 30 years. This concealed the problem of the contact wire icing, or we can say the problem of the contact wire icing has not been highlighted.

Third, the built electrification railways are busy lines conveying passengers and cargoes. The leisure time is short. In the limited leisure period, the growth of icing is difficult to reach the thickness which can affect the operation, so the problem is concealed again.

However, with the continuous extension of the electrification railways, the topographical features of the regions where railways pass will become increasingly complicated. In addition, the leisure time of railways will be extended, so the icing problem will be highlighted.

Now de-icing and anti-icing methods of practical application at home and abroad are mainly manual removal, contact wire thermal running, chemical removal methods, resistive wire de-icing technology, etc.

### 1.2.1 Manual de-icing

Removing snow and ice through human or machines is the most simple and primitive method. It is a time-consuming, inefficient and unsafe operation. The environmental conditions are always harsh during the period of icing, which brings a lot of difficulty for manual de-icing. Currently, many large domestic railways use this method to remove ice covered on the overhead contact wires.



Fig. 1-1. Manual de-icing on overhead contact wires

### 1.2.2 Contact wire thermal running

The ice situation is observed by staff at the railway before the operation of overhead contact wire. The staff determines the seriousness of icing. If the ice thickness reaches the warning level, then the control center starts de-icing operation, letting the electric current flow through the overhead contact wire. The electric vehicles get power from the collect strip, letting the collect strip run to keep touching the contact wires in idle mode, and ice is removed.

### 1.2.3 Chemical de-icing

This method uses chemical de-icer to decrease the freezing point of water in order to prevent icing. The most common and most effective de-icer is CaCl. The Railroad Car Company in Bremen, Germany, has successfully used the de-icer coating device produced

by the Stemmann Technik Company to apply antifreeze to the contact wires. Currently, domestic airports, highways have a practice which is throwing de-icing agents directly. But applying the de-icing agents to contact wires has not been in use. Moreover, the environmental pollution of scattering chemicals is a problem to be considered.

#### **1.2.4 Resistive wire heating de-icing**

Alston, France and Hitachi, Japan developed a de-icing system of overhead contact wire using built-in wire with insulation resistance characteristics, and applied it to railway and tram systems in Japan, France, South Korea, and the UK. The de-icing system is similar to composite conductors used in de-icing of high-voltage transmission lines.

In China, Harbin subway station uses a resistive wire heating to melt ice. Supply power to the power plate, and connect power plate to the resistive wire to heat the contact wire. Although the project which uses the contact wire de-icing program can achieve the purpose of de-icing theoretically, but the de-icing system is lack of experience in successful application and is also lack of the corresponding specifications which are dependent on weather conditions, ice thickness, ice melting current and time, etc.

### **1.3 Major hazards of contact wire icing**

#### **1.3.1 Icing reduces the performance of the contact wire**

The added weight to the contact wires because of icing can increase the tension of the wires, cause the dropper clamp for messenger wire to break, deform the mid-anchor clamp and damage the swivel clip holder. Especially in glaze ice conditions, icicles may grow at the bottom of the clamps for suspension, which may result in the increase of the variation of the elasticity, and lead to the increase of the vertical contact force between collect strip and contact wire. This may reduce the performance of the contact wire. This performance includes two meanings: one is the higher smooth, and the other is the higher kilter. The "higher smooth" means the actual distance between the contact wire and the orbits plane is smaller than the distance of the ideal parallel state; Second. The "higher kilter" means that the contact wire itself is flat and straight all the way, so that the collect strip can run smoothly with a high-speed without any blocks. If there are icicles at the bottom of the contact wires, a hard wear may occur when the collect strip runs. The contact wires can not meet the ideal smoothness requirement, which is the main reason for being off-line of the collect strip, volatility of collect current, and flash. The rising rate of electric locomotive collect strip off-line not only damages the high-speed running locomotive, but also shortens its lifespan.

#### **1.3.2 Icing causes divergence of the contact wire**

The changed shape of cross-section after icing makes aerodynamic characteristics of the contact wire and lines change. Then the added loads under wind may make the contact wire diverge. In order to make the contact wire wear in a uniform manner in the design, the installation of the overhead contact wire should be in the shape of a "Z". The "Z" shape pull-value is generally  $(480 \pm 10)$  mm. If the contact wire diverges, it may break the smooth contact between the collect strip and the contact wire. This not only affects the current collection quality, but also speeds up the wear of collect strip and contact wire.

### 1.3.3 Icing causes an electric arc

Ice covered on the contact wire surface will reduce the conductivity when current flows from the contact wire to the collect strip, and produce electric arc, which can burn out the contact wire and the collect strip. If a heavy icing happened, and it is glaze or hard rim, the thickness of icing is so big that the contact wire is apart from the collect strip, resulting in no current flow, then the locomotive has to stop. There is a huge difference between icing of contact wire and icing of high voltage line. Because as long as the tower won't collapse and the line isn't broken, it still can transmit power with ice on lines.

### 1.3.4 Icing causes insulator flash-over

When it snows and is foggy in winter, ice accretion will coat on the high-speed locomotive's roof surface insulators, and will deposit mainly on the upwind side. The ice is generally 5-10 mms thick, and the maximum thickness can reach over 30 mm. The higher the speed is, the more serious the icing will be. When the locomotive pulls in, the ice will melt due to corona heating, and the contaminated medium in the ice will form a conductor, which can cause short circuit which in turn will cause flashover, cause damage to electrical equipment and affects the normal transport. For the northern electrification railway, the major problem is flash-over of insulator on the roof of power locomotive.

### 1.3.5 Icing leads to galloping of the contact wire

Despite the fact that galloping of the overhead contact wire caused by icing is rare, its hazards are massive. The damage caused to the parts of contact wire in the area influenced by the galloping mainly includes the breakage of positive feeder cable, steadyarm, and dropper clamp, deformation of mid-anchor clamp, and the breakage of cantilever insulators, etc. From 20:43 to 12:22 on February 9th, 2003, on the Xuchang–Mengmiao section of Beijing-Guangzhou Line and Mengmiao-Eastern of Pingdingshan section of MengBao Line, a galloping occurred in the overhead contact wire equipment which was a rare phenomenon in the electrification railway history of China. The galloping amplitude is 1.5m; horizontal amplitude is about 0.6m. It caused large amounts of damage to equipment.

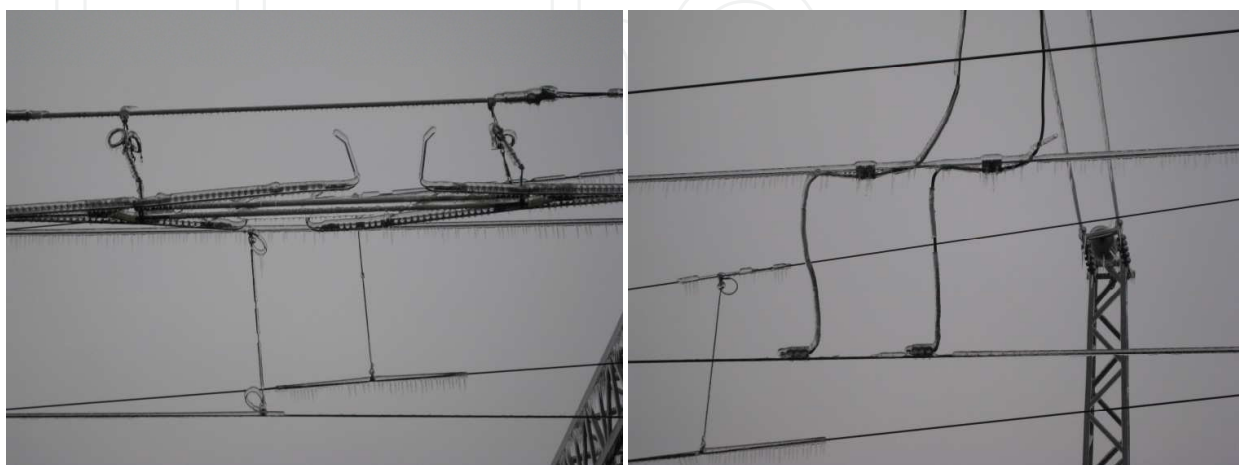


Fig. 1-2. Icing of overhead contact wire

## 2. Characteristics and affecting factors of the icing

### 2.1 Types of icing

Atmospheric icing of structures, which is also called icing or ice accretion, often happens in cold-damp regions. It can be classified into three categories, i.e. Precipitation icing, In-cloud icing and Sublimation icing.

Icing is influenced by factors, such as micro-climate, micro-terrain, wind speed, temperature and content of supercooled water in air, etc. Influenced by the above factors, icing on aerial wires can be divided into several categories according to different taxonomy.

#### 2.1.1 Classifications of ice based on the appearance

Glaze: transparent vitreous, unbreakable and strong in texture with density between 0.6 and 0.9g/cm<sup>3</sup>, can also be called ice slush or clear ice which covers wires with strong adhesive power and never easy to shed.

Granular Rime: ivory opaque with density between 0.1 and 0.3g/cm<sup>3</sup>, loose and crisp in texture with air bubble voids inside, sinuous surface and irregular shape.

Crystalline Rime: white crystal with many air bubbles inside, loose and soft in texture with density between 0.01 and 0.08g/cm<sup>3</sup>, weak adhesive power on wires and easy to shed.

Wet Snow: ivory or offwhite, usually soft in texture with density between 0.1 and 0.7g/cm<sup>3</sup>. Wet snow on wires will turn into hard frozen body when the temperature continues to decrease.

Mixed Rime: ivory, large with many voids, is formed by the alternate freezing of glaze and rime on wire surface, and the density ranges from 0.2 to 0.6g/cm<sup>3</sup>.

#### 2.1.2 Classifications of ice based on formation mechanism

Precipitation Icing: Icing or snow cover formed by freezing rain (supercooled water) or snowflake falling on the wire surface whose temperature is close to 0°C or even below. The supercooled degree of water drops has something to do with the size of water drops. Usually the bigger drops are, the lower degree is. The supercooled degree of little water drops can be several centigrade, while the degree for fog droplets can even be more than ten degrees. Once touching the wires, the supercooled water droplets would freeze. Because the speed of releasing latent heat is slow during the process of freezing, a film of water would appear on the wire surface, and thus glaze is formed. Glaze formed by precipitation icing is the most dangerous to aerial wires because of its high density and strong adhesive power. Freezing rain often happens in America, Canada, Russia China, etc., while snow covering is more common in Japan and the Alps.

In-cloud icing: ice frozen by the supercooled cloud or fog in the air on contact with the wires. Without rain or snow, icing mainly depends on humidity, air velocity etc. This type of icing happens with high frequency in many places and is easy to do simulation study with artificial weather, which is one feature of in-cloud icing. Another is that in-cloud icing can be formed as long as supercooled water drop exists. Small in size, the fog droplets can release the latent heat quickly when freezing. Thus, it won't form a water layer on wire surface. Therefore, in-cloud icing usually produces rime.

Sublimation Icing: a frost formed when water vapor in the air freezes on the surface of things directly. It is also called crystalline rime. Formed through sublimation, it is called sublimation icing. It won't get large because of its weak adhesion and being easy to shed. Therefore, it won't pose a big danger to the aerial wire.

When it comes to transportation system, glaze, mixed rime and wet snow, etc. can be of great danger to it.

## 2.2 Main affecting factors of icing

Generally speaking, the icing of aerial wire is mainly influenced by micro-climate and micro-terrain. The size, rigidity and shape of the aerial wires may also affect the icing, which, however, are not the premier influence.

Micro-climate mainly includes the temperature, wind speed, wind direction, and liquid water content in the air (LWC). These parameters are used in the prediction model of icing. They mainly control the flow and heat transfer in icing process.

Micro-terrain mainly includes the altitude of the wire, the local topography, water distribution, etc. These parameters may not be manifested in the prediction model of icing. Their major functions are to affect the heterogeneity of flow field and therefore causing different icing.

Temperature is the key influencing factor of icing. Generally speaking, the temperature of icing is always below 0°C. However, if it is too cold (below -10°C), icing won't occur. If the supercooled degree of water drops is high, icing would happen even over 0°C (about 1°C), and this will form dense glaze. The general tendency is that the colder, the heavier of icing.

Wind speed is also an important influencing factor of icing. It will ice only when the supercooled water droplets touch the wire surface. The wind sends the supercooled water drops to the wire surface, and the wind speed also affects the heat transfer in the process of icing. Therefore, the higher the speed of wind is, the more supercooled water drops can touch the wire surface; the more easily the latent heat released in the process of icing can be flew away, and the more icing on wire surface will be.

Direction of wind also has certain influence on icing. The wind direction mainly affects the effectiveness of supercooled water drop delivery. If the wind direction is perpendicular to the wires, the delivery is the most effective; if the wind direction is parallel to the wires, the delivery is the least effective, hence less icing.

Liquid water content (LWC) exerts an important influence on icing. It will not only influence the speed of icing but also the types of icing. Generally speaking, if LWC is low and diameter of the droplets is small, rime is formed and icing develops slowly, whereas if LWC is relatively high and diameter of the droplets is comparatively big, glaze is formed and icing develops quickly. If the LWC is very high and diameter of the droplets is very big, rain is formed.

## 2.3 Comparison between icing on contact wires and on aerial high-voltage transmission lines

### 2.3.1 Differences in structure

High-voltage transmission wires are steel-cored aluminum strands while most contact wires of electrification railway are copper-alloy hard wires with glossy finish. Therefore, with



difference in wire surface, the icing might also be different. Nowadays, the research on the influence of wire surface on icing is seldom touched.

The hard contact wire has many bearing points and short in span (less than 65m) in which the suspension is well-distributed, often with an interval from 8m to 12m, and therefore it can be regarded as a straight line which won't twist or wave when icing; high-voltage transmission line is catenary with huge span (300-500m), which will twist when icing and wave drastically in wind.

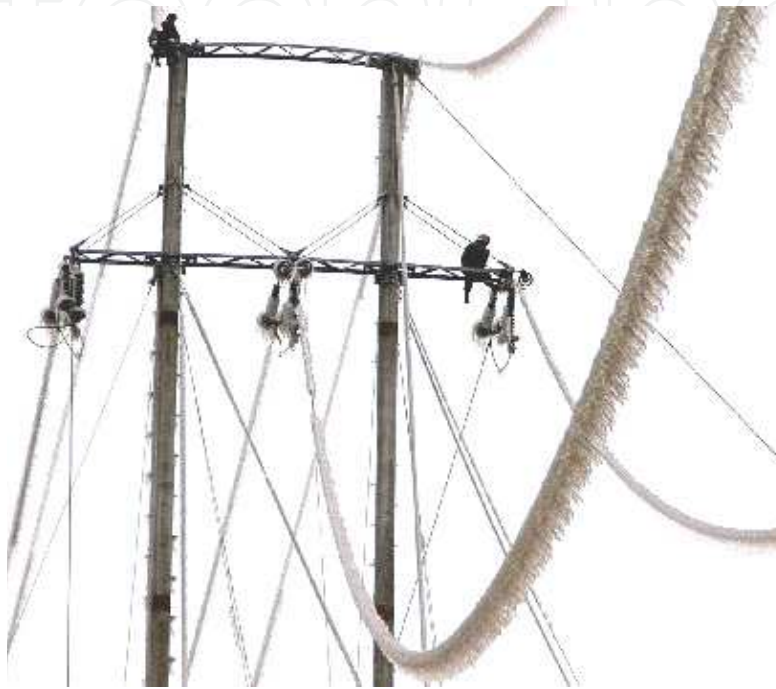


Fig. 2-1. Icing of high-voltage line

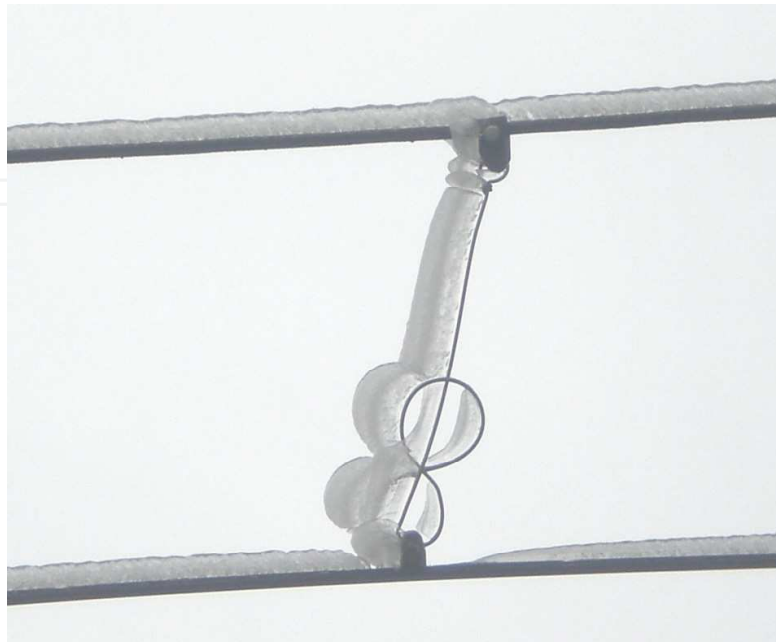


Fig. 2-2. Icing of contact wire

### 2.3.2 Differences in height

There is a huge difference in height between electrification railway contact wire (usually about 6m) and high-voltage line (ranges from tens of meters to hundreds of meters). Therefore, the influence of wind speed varies. Influenced by air-flow boundary layer, the speed of surface wind is weaker than that of high-altitude wind. Since wind dominates the delivery of supercooled water drops to the wire surface, generally speaking, the icing of contact wire will be weaker than that of high-voltage line under the same meteorological parameter and geographical and topographical conditions. The influence of other meteorological parameters makes no difference between the two.

## 3. Experimental study of icing and ice melting on contact wires

### 3.1 Experiment setup

This experiment is made in an artificial environment chamber in a key laboratory of high efficiency heat exchange technology and equipment of Hunan province, China. Low-temperature Freon solution produced by the chillers flows through a wall-hung heat convection tube which makes room temperature as low as -18 degrees Celsius.

A circular wind tunnel is set in the environmental room with a test section which is made of Plexiglas and whose cross section size is 350×350mm (fig. 3-1, fig. 3-2). Three specimens are arranged in the test section: a real CTS120 contact wire with a calculation area of 121mm<sup>2</sup>, the unit of mass for reference 1082kg/km, and a density of 8.94g/cm<sup>3</sup> is in the middle. Its electric resistance in 20°C is 0.01777Ω/m. The other two are cylinder specimens. The cylinder specimens have the same diameter and shape as CTS120 (with a built-in electric heater, fig3-3). This experiment studies the influence of wind speed, temperature and liquid water content on icing and ice melting process.

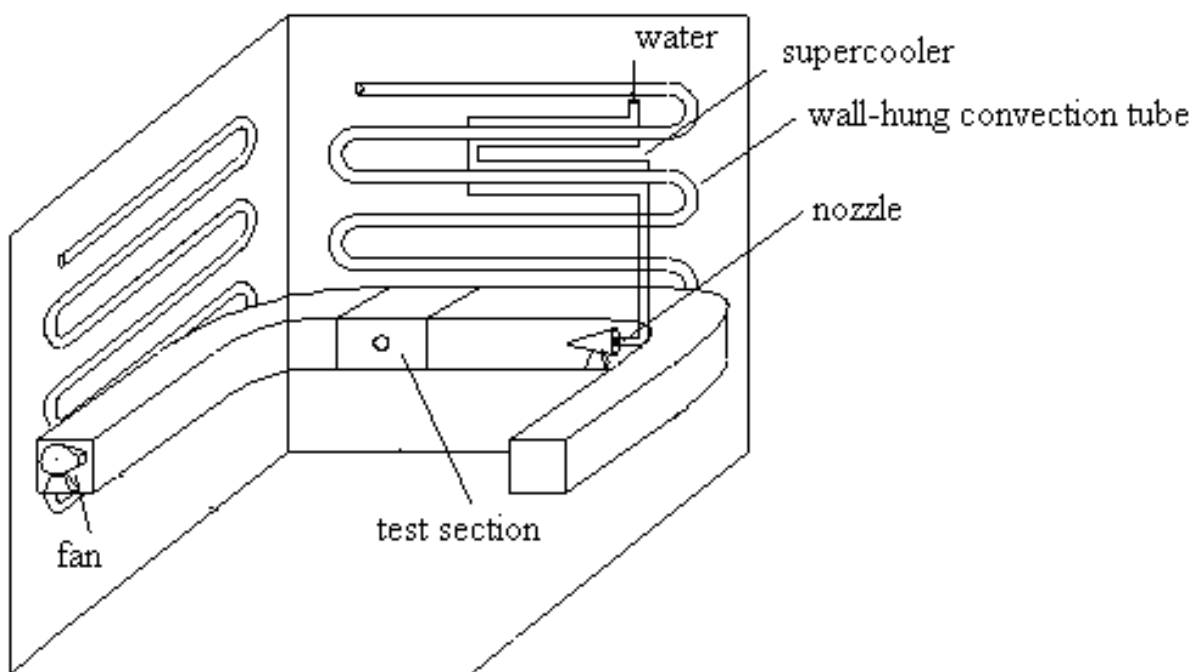


Fig. 3-1. Experiment system schemes

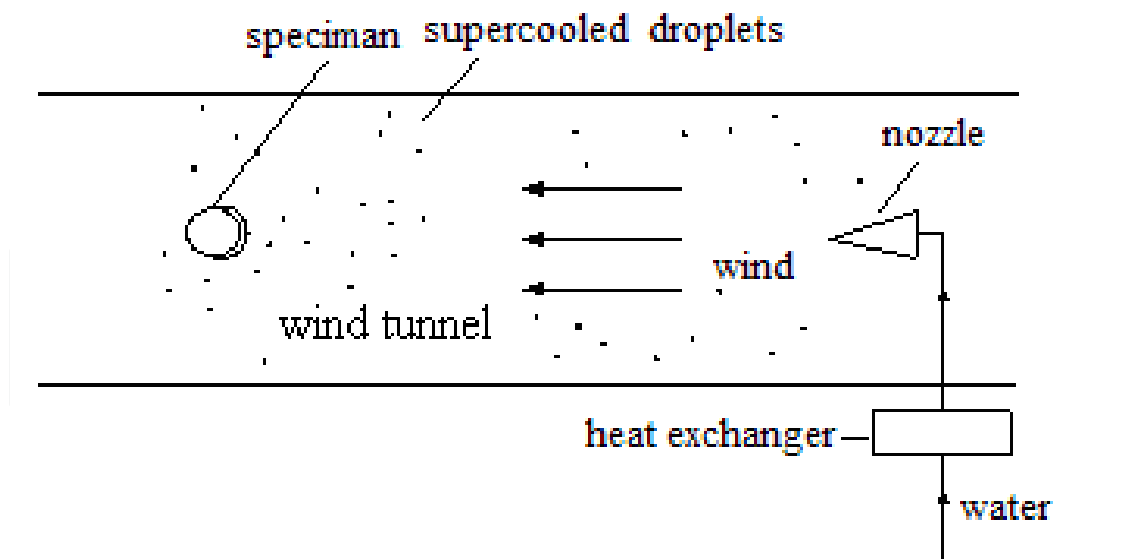


Fig. 3-2. Isometric view of wind tunnel

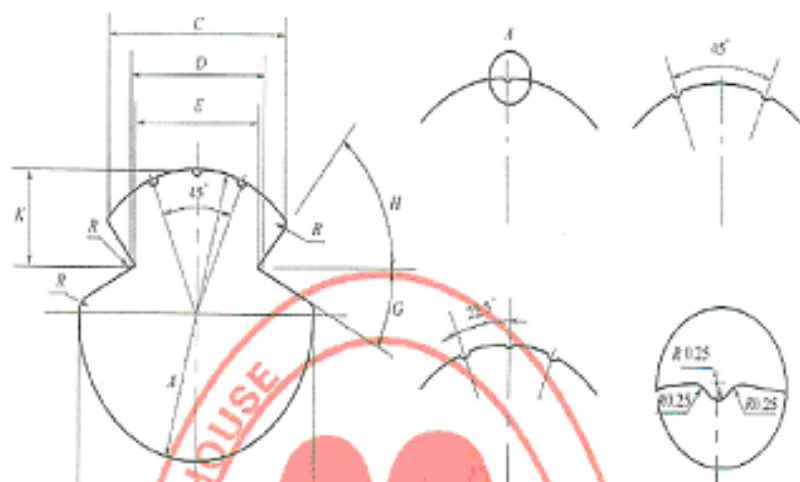


Fig. 3-3. CTS120 contact wires shapes

### 3.2 Fitting formula of ice accretion

According to the summary of Henry, there are over 20 models used to predict such icing problems as glaze and rime. These include the Imai model (wet growth process), Lenhard model (a simple formula to calculate the weight of the ice), Goodwin model (dry growth process), Chaine model (dry growth process, but shape of the icing is the uneven oval), and Makkonen model (considering the existence of icicles).

The formula is based on the Imai model determining ice load by heat transfer process on wire surface and the icing intensity is proportional to negative air temperature section (-T), and is irrelevant to precipitation.

$$\frac{dM}{d\tau} = C_1 \sqrt{VR} (-T) \quad (1)$$

Where

$V$  : wind speed, m/s;

$T$  : air temperature, °C;

$t$  : time, hours (h);

$M$  : ice mass, kg.

$C_1$  : constant

Equation (2) can be drawn from (1)

$$M = C(V(-T)t)^{4/3} \quad (2)$$

The fitting formula for ice mass calculation based on experimental data ( $T=-2^\circ\text{C}$ ,  $V=2\text{m/s}$ ) is as follows

$$y = 0.00621t^{4/3} \quad (3)$$

Comparing equation (1) with (2), we can get

$$M = 1.7927 \times 10^{-3} \sqrt{V(-T)} t^{4/3} \quad (4)$$

Fig.3-4 shows the curves of experimental data and fitting data under different conditions ( $T=-2^\circ\text{C}$ ,  $V=2\text{m/s}$ ;  $T=-2^\circ\text{C}$ ,  $V=6\text{m/s}$ ). Experimental data are very much in line with that of fitting formula. Ice load on contact wires with random length can be calculated by:

$$M = 8.9635 \times 10^{-3} \times l \times \sqrt{-VT} t^{4/3} \quad (5)$$

Where

$l$ : wire length, m

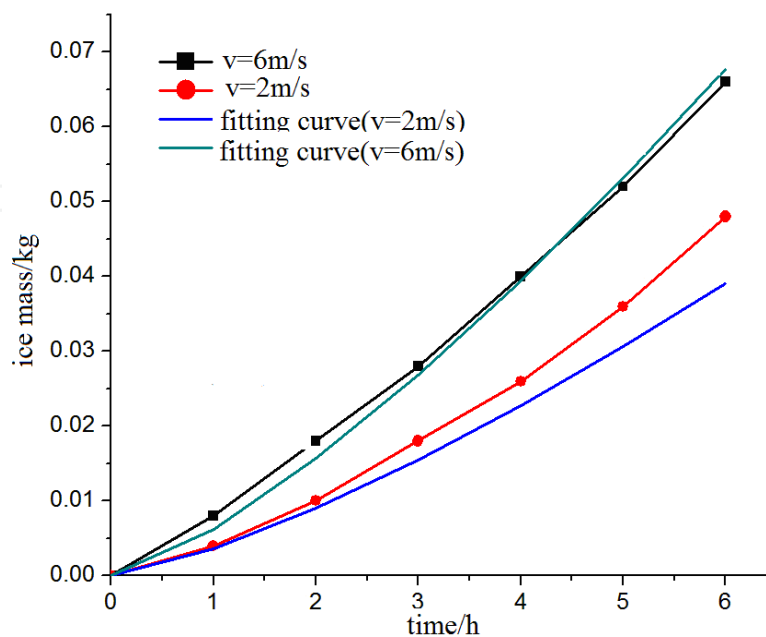


Fig. 3-4. Ice growth with time

### 3.3 Experimental results and analysis of ice accretion

This experiment mainly concerns the influence of air temperature, air speed and liquid water content, etc, on ice accretion.

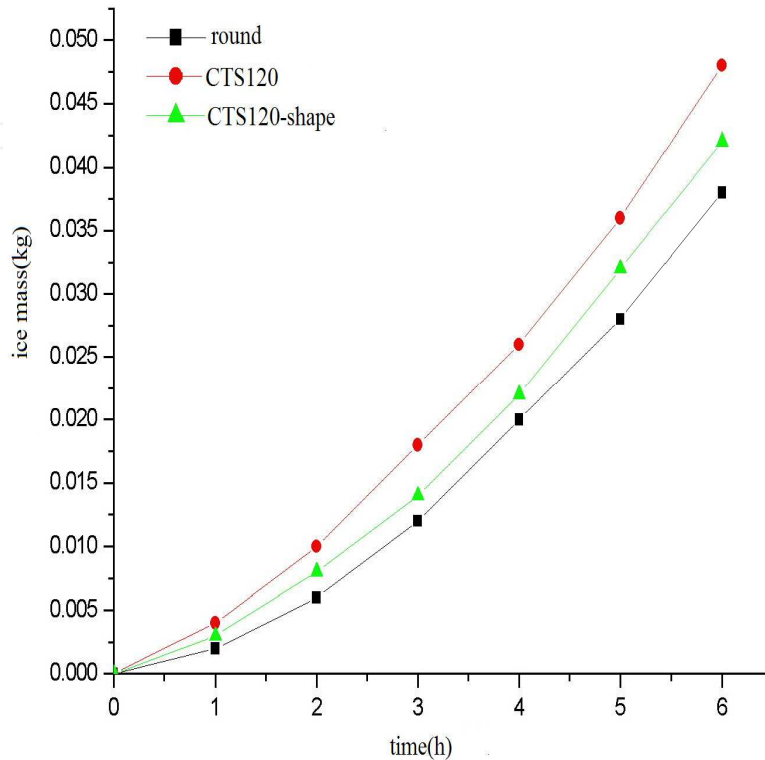


Fig. 3-5. Ice growth of different specimens

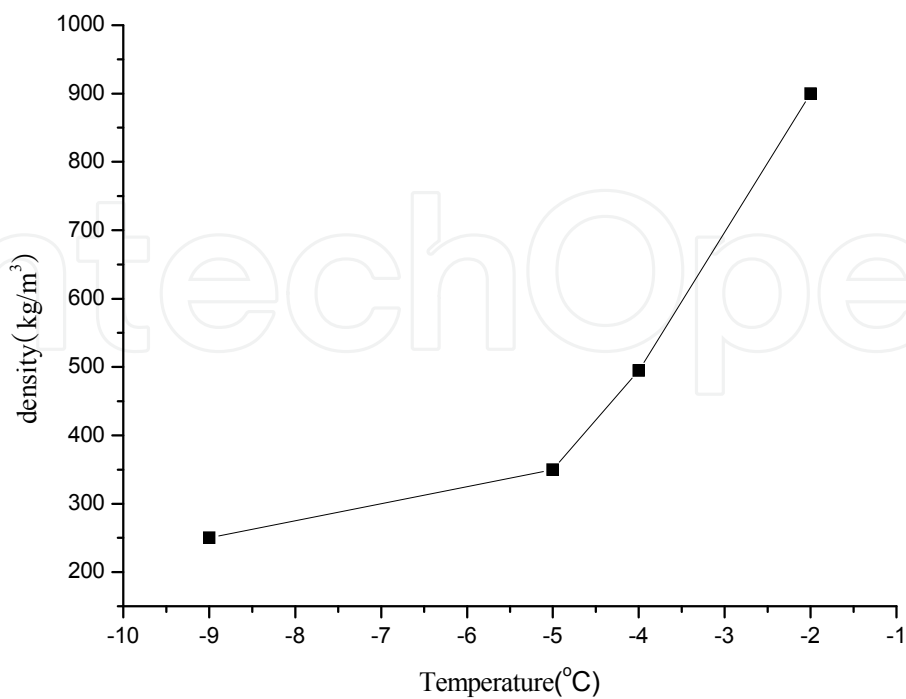


Fig. 3-6. Ice density variation with time



Fig. 3-7. Photos of ice accretion

From fig.3-5, 3-6 and 3-7, we can draw the following conclusions:

1. The wind speed has significant influence on icing and the higher the wind speed is, the bigger the ice density will be.
2. Increasing air temperature leads to increasing ice density but decreasing ice thickness.
3. Ice type begins to change in  $-4^{\circ}\text{C}$ . When the temperature is higher than  $-4^{\circ}\text{C}$ , large mixed glaze ice or glaze ice will form; when the temperature is below  $-4^{\circ}\text{C}$ , rime ice will form.
4. Within experimental wind speed limits, the influence of wind speed on ice type is not obvious. Ice type is mainly affected by air temperature, and, the increase of wind speed leads to the increase of adhesion between the ice and contact wires.

### 3.4 Icing melting process

Fig.3-8 shows uniform cylindrical glaze ice on the round specimen built in electrical heater. Table 3-1 presents the ice melting time under different ice thickness with the electrical power 100W, and the air temperature  $-5^{\circ}\text{C}$ . The ice melting process is divided into two stages. The first stage begins to melt ice sleeve to the top and the second stage begin from the end of the first stage to complete falling off the specimen.

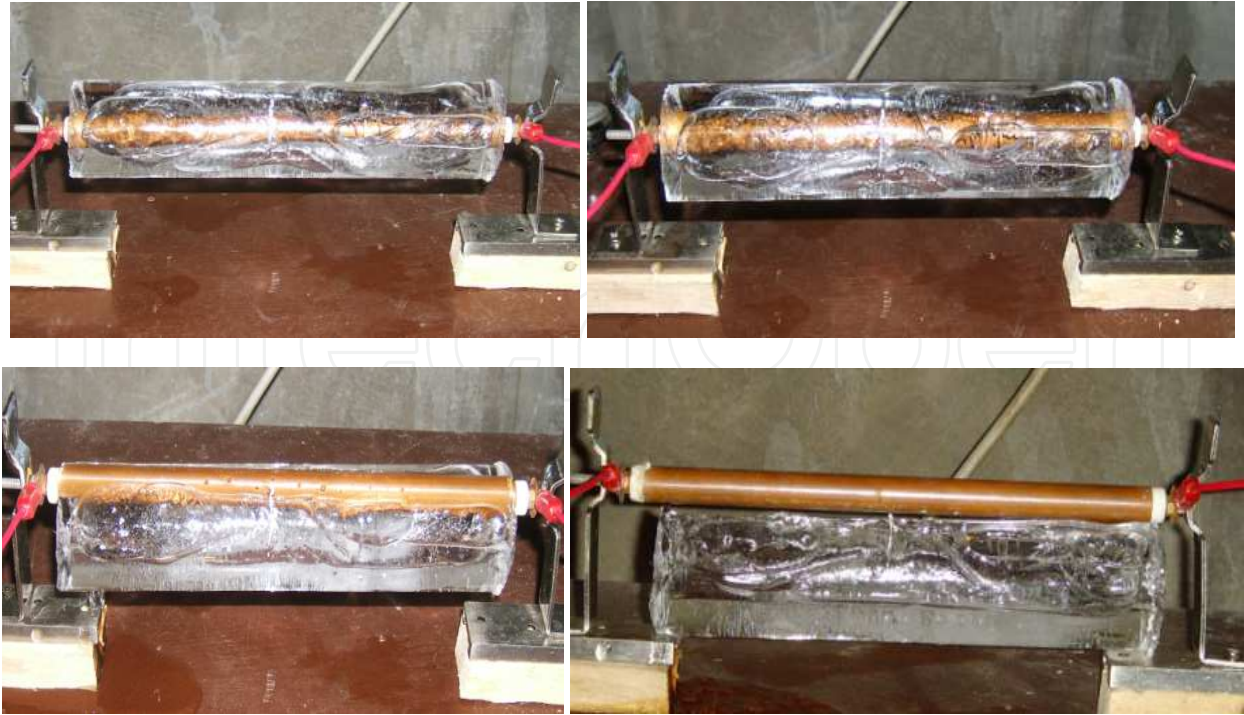


Fig. 3-8. Photos of ice melting process

Ice thickness (mm)	Wire type	Ice melting time (s)		Ice density (kg/m <sup>3</sup> )
		The first stage	The second stage	
4	Round	116	18	884.36
	CTS120-shape	330	45	901.25
7.5	Round	382	34	912.56
	CTS120-shape	628	96	932.18
12	Round	554	53	905.68
	CTS120-shape	804	124	914.24
16.5	Round	728	33	879.89
	CTS120-shape	856	58	886.47
29	Round	1425	152	901.56
	CTS120-shape	1621	231	907.30

Table 3-1. Ice thickness and ice melting time

The experiment results show that in the same thickness, ice melting time of CTS120-shape specimen is longer than that of round wire and the possible reasons are:

1. The CTS120-shape specimen is made from steel tube and its heat or contact resistance is higher than the round specimen.
2. The two grooves of CTS120-shape are filled with water, causing the ice melting process relatively slow, and affecting the upstairs of ice sleeve.
3. Ice on the two specimens has different density.

The fitted curves by the least square method are shown in fig.3-9.

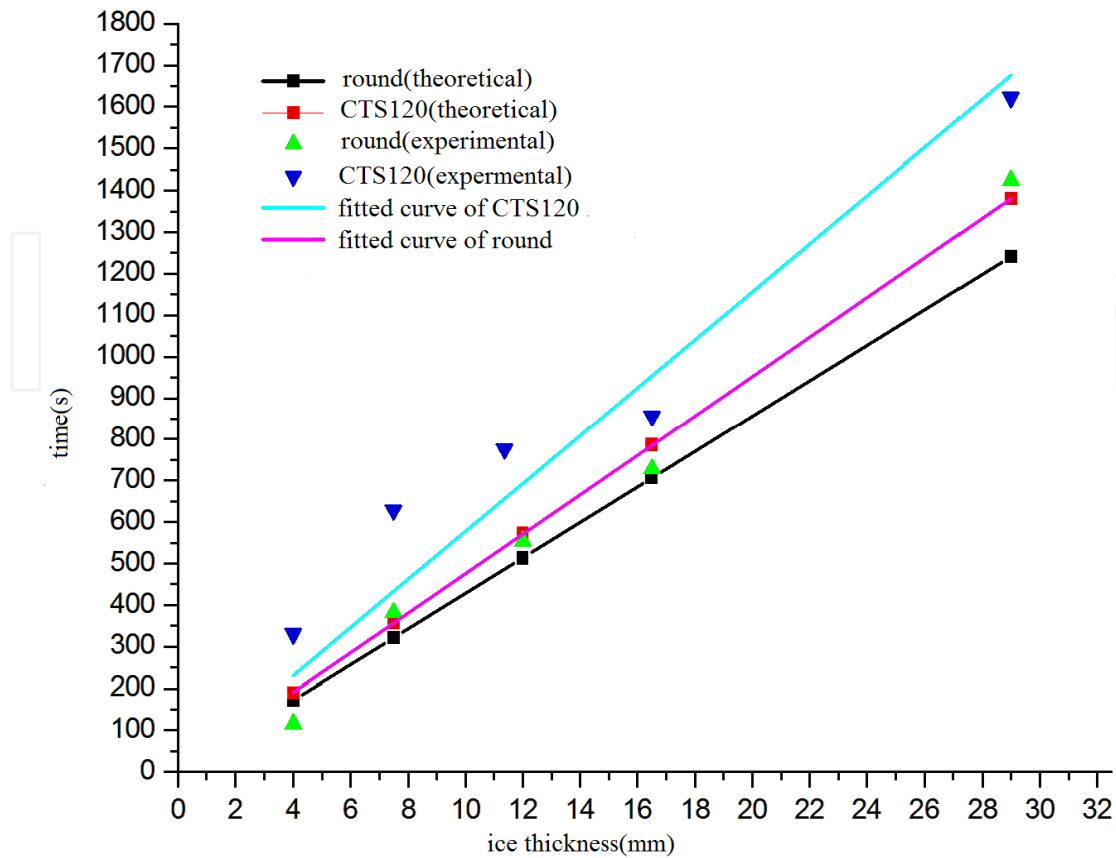


Fig. 3-9. Fitted curves of ice melting time & ice thickness

The linearized expression of ice melting time of round specimen:

$$\tau = 47.62 x \tag{6}$$

The linearized expression of ice melting time of CTS120-shape:

$$\tau = 57.77 x \tag{7}$$

$\tau$ : ice melting time of the first stage(s)  $x$ : ice thickness(mm)

The total ice melting time is equal to the sum of the first and second stages ice melting time. It is found that the ice melting time of the first stage of round specimen account for 8.7% of the total time and that of CTS120-shape specimen accounts for 13% of the total time.

By correction, the formula for ice melting time of round specimen is:

$$\tau_{total} = \varepsilon_1 \times \tau = \frac{2\varepsilon_1 R_i \rho_s \cdot h_{sf}'}{I^2 R_e} \cdot (R - R_i) \tag{8}$$

The formula for CTS120-shape specimen is:

$$\tau_{total} = \varepsilon_2 \times \tau = \frac{2\varepsilon_2 R_i \rho_s \cdot h_{sf}'}{I^2 R_e} \cdot (R - R_i) \tag{9}$$



where  $\varepsilon_1 = 1.22$ ,  $\varepsilon_2 = 1.39$ .

For the existence of grooves in CTS120-shape specimen, in the same ice thickness, its ice cover is more than that of the round specimen and its ice melting time is 1.18 times longer than that of the round specimen.

## **4. Expert system of icing and icing melting**

### **4.1 Design principles of ice melting**

Due to railway's structural characteristics, the automatic ice melting device cannot be used on the charged contact line for the time being.

1. According to the train schedule, the start instruction of ice melting is given by an expert system before the operation of the maintenance line.
2. Control the ice melting time within 20 minutes.
3. In order to guarantee no interference with railway communications and no damage to communication equipment, railway tracks and the corresponding ground equipment can not be used in ice melting grounding contact.
4. Start ice melting devices when the ice thickness is over 5mm.

### **4.2 Ice melting schemes**

#### **4.2.1 Melting by direct short circuit method on AT**

Because of the small leakage resistance of AT traction nets and self coupling transformer, the short-circuit current is great. The short-circuit current on AT set by JEC of Japan is 25 times than the normal current. Therefore, the use of a short-term (2 min) short circuit on AT for ice melting is available.

#### **4.2.2 DC ice melting**

DC ice melting devices are not affected by stray inductance and capacitance of contact wires is highly efficient. The main equipment includes a step-down transformer and single phase linear DC stabilized voltage source connected to contact wires during ice melting.

### **4.3 Expert system of icing and icing melting**

This expert system is based on electrical current de-icing strategy and Labview language. The main objectives of this study are:

1. To estimate ice type according to the meteorological parameters such as air temperature, relative humidity, wind speed, which are obtained by corresponding sensors.
2. To calculate the current required to melt ice in a given thickness and a given time interval or the time required to melt the ice buildup for a given current according to the air temperature, wind speed, air humidity, and ice density.
3. To predict ice accretion types, and control ice melting process based on both theoretical and experimental studies.

With the help of video cameras, it can make real-time analysis, monitor, control on-line work station and stop the melting process in advance in case of cable overheat. Labview serving as a good bridge between hardware and software makes weather parameters collection easy. In some circumstances, it is necessary to use the technology of Labview& Datasocket to realize data share between the data collection and control room.

#### 4.3.1 Software structure

This expert system has two key functions, one is the ice type estimation (according to meteorological parameters), and the other is the control of ice melting strategy (provide values of the current required to melt a given buildup of ice in a given time interval or the time required to melt the ice buildup for a given current). The man-machine conversation (file management), data acquisition, data display, data analysis, preservation, and other functions, are also achieved in this software. The structure of the software is shown in Fig.4-1.

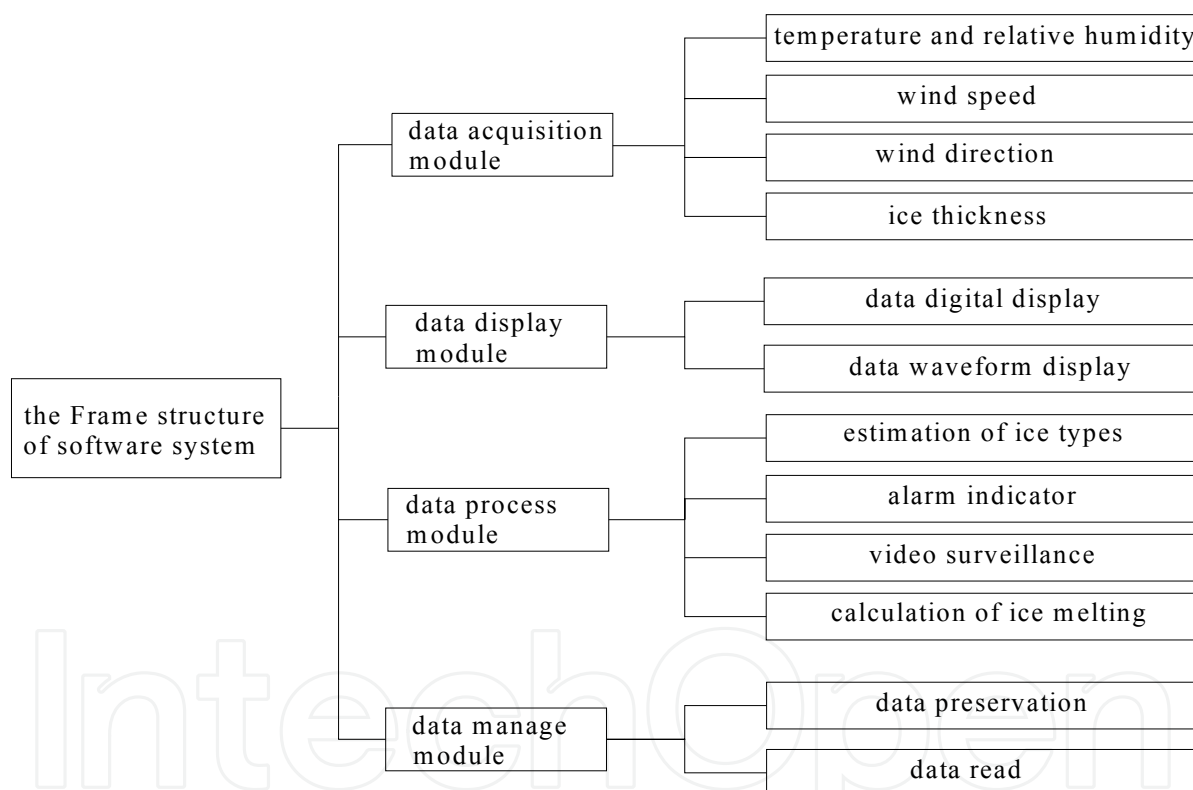


Fig. 4-1. The software's structure

Data acquisition module can collect air temperature, relative humidity, wind speed, wind direction, ice thickness and the real-time video of the scene. Ice type estimation module can estimate ice type according to wind speed, air temperature and air humidity via experimental investigations. Electrical de-icing calculation module can provide values of the current required to melt ice in given thickness and given time interval or the time required to melt the ice buildup for a given current according to meteorological parameters. All data will be recorded in computers for subsequent search, analysis, display, print, and research in data management module.

### 4.3.2 Logic structure

The logic chart of the software is shown in Fig.4-2. If the weather is likely to cause icing, the system will sound the alarm to warn the operator. When ice thickness exceeds the specified value, the light or voice alarm indicator will remind the operator that melting is needed. If we choose the off-line analysis, we need to enter the needed data manually, which helps the operator to estimate when the cables are iced, and whether the sensors in the scene are broken.

With the help of the video camera, we can control the melting process in real-time. For example, when the given melting time is up, but the video shows that the ice has not fully shed yet, the system will give an instruction to continue melting the ice. However, if, within the given time, the video shows that the ice has been shed, the system will give a stop instruction to stop the ice melting process so as to prevent the wire from being burnt.

The interfaces of the software are shown in fig.4-3.

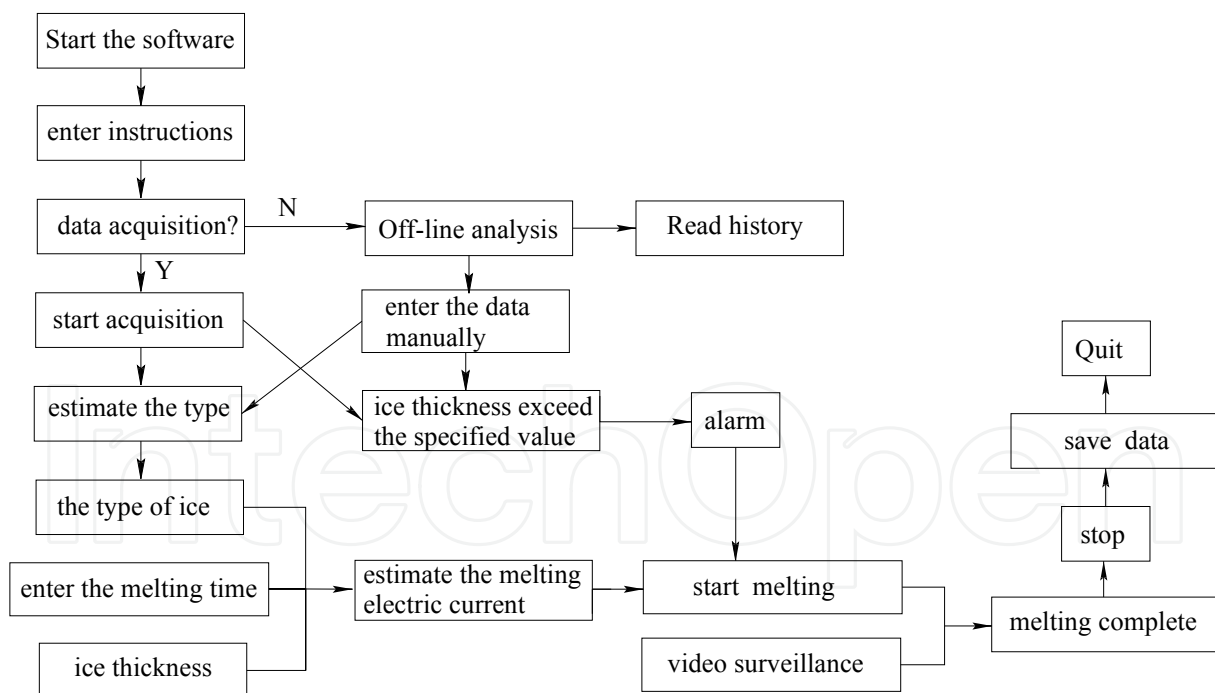


Fig. 4-2. Logic chart of the software

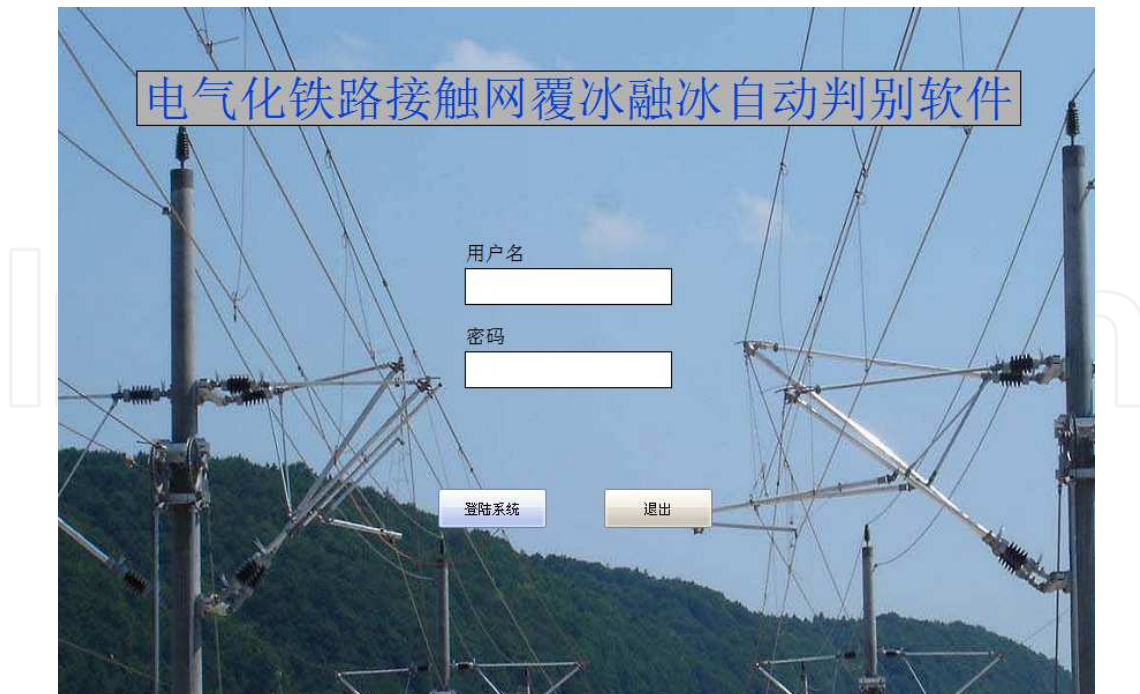


Fig. 4-3. Interface of the software

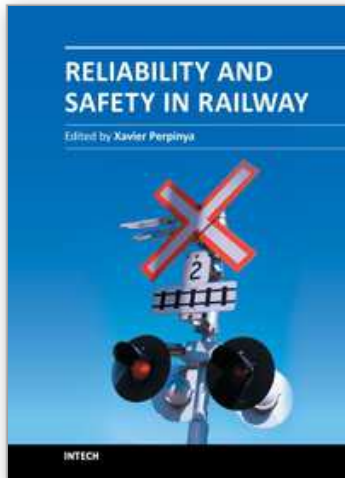
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In railway applications, performance studies are fundamental to increase the lifetime of railway systems. One of their main goals is verifying whether their working conditions are reliable and safety. This task not only takes into account the analysis of the whole traction chain, but also requires ensuring that the railway infrastructure is properly working. Therefore, several tests for detecting any dysfunctions on their proper operation have been developed. This book covers this topic, introducing the reader to railway traction fundamentals, providing some ideas on safety and reliability issues, and experimental approaches to detect any of these dysfunctions. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, and engineers.

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