Design and Analysis of Data-driven Intelligent Control Systems for Deicing and Snow-Melting of Extremely Cold Areas

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Abstract: Aiming at the problem of deicing and snow-melting for extremely cold areas, a novel method is proposed to solve the problem. Firstly, the preliminaries for deicing and snow-melting are introduced based on the principle of conservation of energy; secondly, the temperature setting model is established for the situation of completely deicing and snow-melting; thirdly, combining with the real-time data obtained by sensors on the bridge desk and intelligent control theory, a newly environmental friendly automatic thermal control system for deicing and snow-melting is put forward; lastly, the system is installed on the Enshi Nanhe Daya Bridge in Hubei Province of China, and the actual tests reveal that the effective of the deicing and snow-melting is evident.

Key Words: Deicing and Snow-Melting, Temperature Setting, Intelligent Automatic Thermal Control System

1 INTRODUCTION

Icing phenomenon is common for the dangerous sections of the extremely cold areas, such as the bridge, ramp, and tunnel and so on. The sections are narrow and expose in the air absolutely. Importantly, once snow or icing problem occurs, it is impossible to clean the snow and ice, which will bring out the transport disruptions or accidents, not only affecting the traffic safety, but also restricting the pace of economic construction and national defense construction. Therefore, it is critical to solve the problem. Considering the secondary hazards for the traditional methods about deicing and snow-melting and the great energy consumption for some newly technologies, developing an energy saving, environment friendly, high efficiency automatic thermal control system is so emergent. Some scholars made some researches aiming at the bridge, roads and tunnel, respectively. References [1-9] made some experimental research from the angle of carbon fiber wires, including resistance property, laying interval, melting icing methods and effects and so on. Meanwhile, the intelligent control schemes for deicing and snow-melting were designed and analyzed, and the simulate experiments were made [10-11]. However, the related criterion and reports about the problems for engineering application have not worked out yet. In addition, various areas have different geographical and climate features, it is difficult to copy and imitate the design specifications.

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Based on the facts above, aiming at the problem of deicing and snow-melting problem for extremely cold areas, the thesis regards the carbon fiber as the heating conductors, designs an automatic thermal control system for deicing and snow-melting, which is environmental friendly, energy saving, and high efficiency. Finally, the engineering practices are made for Enshi Nanhe Daya Bridge in Hubei Province of China, and the results show that the effective of the deicing and snow-melting is evident.

2 PRELIMINARIES FOR DEICING AND SNOWING-MELTING

The snake-like is adopted with wire mesh for heating cable, and then the mesh is laid between the structures of asphalt concrete as Fig. 1. The system will be switched on when the temperature and humidity reach the set values, and then the electrical energy is converted into heat, which raises the inner temperature of the concrete. Meanwhile, the heat is delivered to the bridge deck via heat-conduction for certain time, obtaining the purpose of snow-melting. If the heat is delivered continuously, the temperature of melting water will maintain above zero, which will prevent the melt-water from icing up. In order to reduce the heat passed down and the heat loss, the insul**a**tion is laid under the structure of concrete, which can reduced the temperature in the reinforced concrete beams, making the temperature stress within safe levels.

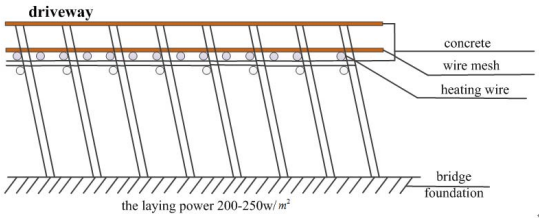


Fig. 1 Sketch for Installation of Carbon Fiber

In accordance with the Energy Conservation Law [12], the problem for deicing and snow-melting can be concluded as a mathematical formula, so that the feasibility of application carbon fiber in deicing and snow-melting and various influences on deicing and snow-melting for bridge deck can be verified. And the heat balance equation can be expressed as formula (1), meanwhile the mechanism [13] of thermal conduction about deicing and snow-melting is shown as Fig. 2.

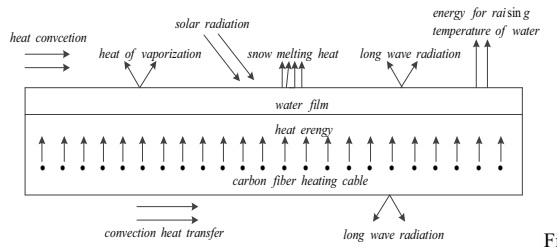


Fig. 2

Heat transfer mechanism of snow-melting for bridge deck

The relationship between these independent variables mentioned above can be denoted as formula (1):

$$P\Delta t = m_c c_c \Delta T_c + m_i c_i \Delta T_i + m_i Q_i + Q_s \quad (1)$$

Where, P denotes the heating power of the carbon fiber, and Δt is on behalf of the electrifying time; m_c、c_c、ΔT_c represent the quality, specific heat and the warming temperature of the concrete respectively. Simultaneously $m_c = \rho_c V_c$, where ρ_c、V_c signify density and volume of the concrete. Similarly, m_i、c_i、ΔT_i denotes the quality, specific heat and the warming temperature, where $m_i = \rho_i V_i$, and ρ_i、V_i represent the density and volume of ice snow respectively. Lastly, Q_i denotes the heat of fusion for ice snow, and Q_s represents the sum of heat loss from concrete, ice, snow, and the outside environment during deicing and snow-melting.

3 TEMPERATURE SETTING FOR DEICING AND SNOW-MELTING OF BRIDGE DECK

In order to keep the bridge open, not only does the snow need to be melted, but also the rain and the melt water required to be prevented from freezing. However, the heat is radiated gradually via the air because of the wind blowing from the bridge deck, leading to the water exposed to the air freeze. Therefore, the comparable amount of heat must be supplied so that the temperature of water on the bridge maintains above zero, and the sketch [14] for deicing and snow-melting is shown as Fig. 3.

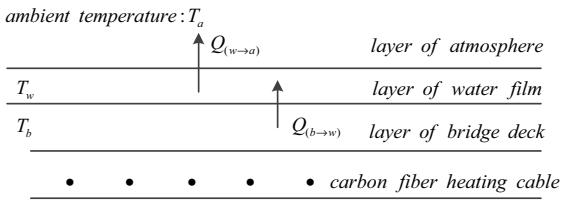


Fig. 3 Diagram for deicing and snow-melting

It is obviously that the heat meets the formula (2) as below:

$$Q_0 = Q_{(b\to w)} = Q_{(w\to a)} \quad (2)$$

Where, Q_0 denotes the draw-out heat from the carbon fiber towards up, $Q_{(b\to w)}$ represents the heat from the bridge deck to the melt water, $Q_{(w\to a)}$ is on behalf of the heat from the melt water to air, and their units are all W/m^2.

$$Q_{(b\to w)} = \alpha_w (T_b - T_w) \quad (3)$$

$$Q_{(w\to a)} = \alpha_a (T_w - T_a) \quad (4)$$

Where, α_w and α_a denote the heat transfer coefficient from the bridge deck to melt water and from the melt water to air respectively, and their units are all W/ (m^2.K); T_b and T_w represent the temperature of bridge and melt water respectively, and their units are all K; in addition, T_a is on behalf of the outsider temperature, and its unite is K, too.

According to (2) ~ (4), we can obtain the conclusion as below:

$$\alpha_w (T_b - T_w) = \alpha_a (T_w - T_a) \quad (5)$$

Then T_w can be achieved from the formula (5), and it can be expressed as following:

(6)

Then $T_w > T_i$ considering that the temperature of melt layer is greater than the setting temperature of melt water, and then the relationship between them can be denoted as in another way as below:

$$T_w = (\alpha_w T_b + \alpha_a T_a)/(\alpha_a + \alpha_w) > T_i \quad (7)$$

Arranging the formula (7), T_b can be expressed as below:

$$T_b > [(\alpha_a + \alpha_w) T_i - \alpha_a T_a]/\alpha_w \quad (8)$$

In other words, the water temperature will maintain above the freezing point of water when the temperature keeps the variation range above, preventing the water on the bridge freezing.

4 INTELLIGENT CONTROL SYSTEM FOR DEICING AND SNOW-MELTING

Expect for maintaining the operational stability of the system for deicing and snow-melting, it needs to guarantee the effect of deicing and snow-melting and save the resources simultaneously. In other words, the operational costs and effect of deicing and snow-melting should be considered into it at the same time so that the configurations are optimized. Therefore, cooperation among Central South University, Chongqing Jiaotong University and Chongqing Wisdom.Q Heat Equipment Company is conducted, obtaining a novel idea, which considers that if rainfalls and snow are judged by system, the system is switched on and advances to preheating step. Subsequently, the system will remove to the snowfall monitoring step after a certain time. And then system starts to work automatically as long as the snowfall is detected. When the temperature reaches the setting value, the system removes to the deicing and snow-melting stage. The process for deicing and snow-melting is shown as Fig. 4.

Based on the process mentioned above, an automatic control system is put between the carbon fiber and the electronic power, which can not only realize the purpose of deicing and snow-melting, but also can maintain the system operate efficiently and economically, and the control flow chart is shown as Fig. 5.

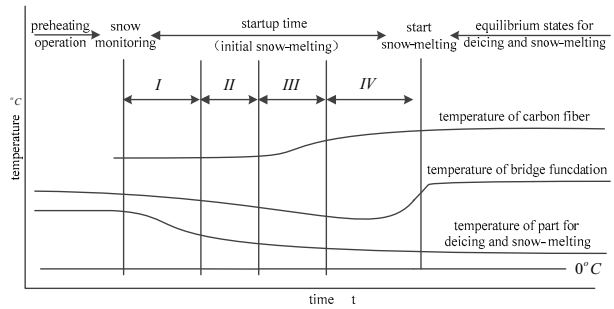


Fig. 4 Sketch for deicing and snow-melting

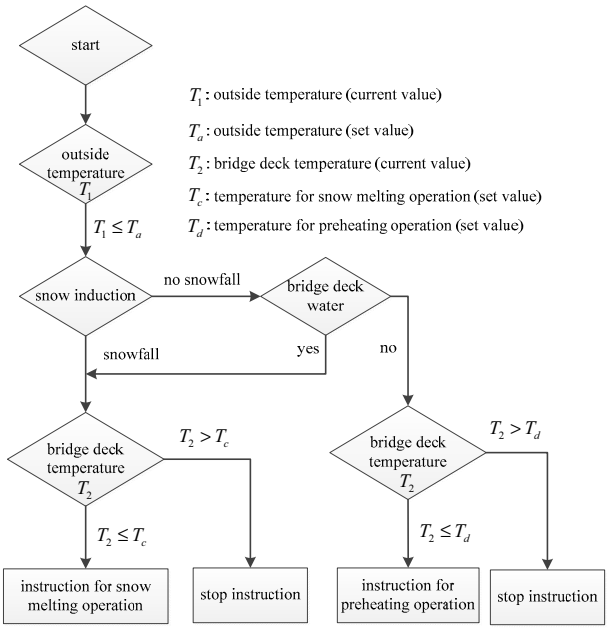


Fig. 5 Automatic Control flow chart for deicing and snow-melting

As can be seen from the Fig. 5 that, only the temperature and humidity reaches at the assigned values at the same, the system will start to work smoothly, which realizes the target of energy saving and environment friendly.

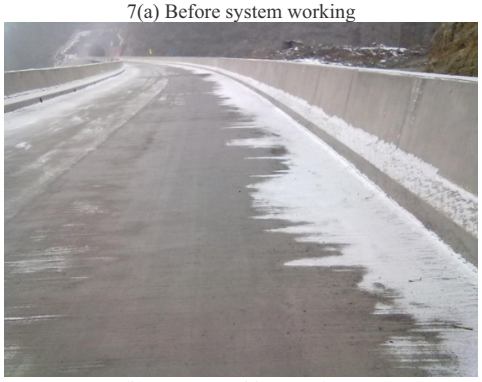
5 EXAMPLE FOR SYSTEM ANALYSIS

Aiming at the actual circumstances of the Enshi Nanhe Daya Bridge, an optimal designing scheme is put forward. Firstly, the insulation layer is put upon the structure of concrete; secondly, the heating cable is laid as snake-like with wire mesh, and then the mesh is laid between the structures of asphalt concrete; thirdly, the system is tested and debugged. If the system can work normally, the concrete will be watered on the wire mesh, and then the bridge deck can be formed by freezing, and the specific depicts can be shown as Fig. 6.

The auto-system for deicing and snow-melting is installed on the Enshi Nanhe Daya Bridge in Hubei province of China, and the results of deicing and snow-melting is compared and analyzed under different situations. Where, the effect sketch for deicing and snow-melting when the thickness of the snow is 0.5cm, the outside temperature is 2.5 ℃ and the bridge temperature varies from -1℃ to 0.5℃ is shown as Fig. 7(a) ~ 7(b).

Fig. 6 Depicts of construction for deicing and snow-melting

7(a) Before system working



7(b)System working 20minutes

Fig. 7 Comparison chart for snow-melting effects

As can be seen from the Fig. 7(a) and Fig. 7(b), it takes 20 minutes to melt the snow in the middle of bridge when the thickness of the snow is 0.5cm, the outside temperature is 2.5°C and the bridge temperature varies from -1°C to 0.5°C. There is some snow on the margin and snow residual like ice cream in the middle. And the bridge temperature is close to the freezing point, but the outside temperature is above zero, so that it only needs short time to melt the remaining

snow on the bridge. In a word, practices show that expect for apparent effect for deicing and snow-melting, the system has some advantages, such as high mechanical strength, long lifespan, strong resistance to pull and high efficiency of electro-thermal, contributing huge value for our society.

6 CONCLUSIONS

In this paper, aiming at the problem of deicing and snow-melting for bridge deck, a new environmentally friendly auto-system for deicing and snow-melting is proposed by Chongqing Wisdom Heat Energy Equipment Company, which applies the combination carbon fiber with the wire mesh together in the structure of asphalt, and then the bridge deck is warmed while the concrete is heated, obtaining the purpose of deicing and snow-melting. The system is installed on Enshi Nanhe Daya Bridge in Hubei Province of China, and the actual tests reveal that the effective of the deicing and snow-melting is evident.

REFERENCES

[1] ZHANGQian-wen, ZHAOYan-hua, WUZhi-min. Deicing Performance of Carbon Fiber Heating Wires Embedded in Concrete Pavement . Journal of Highway and Transportation Research and Development, Vol.32, No.2, 41-48, 2015.

[2] HOU Xuemei. A new system of snow-melting and deicing. Journal of Xi'an University of Posts and Telecommunications, Vol.19, No.3, 74-76, 2014.

[3] LI Yan-feng, HU Shi-yang, WU Hai-qin, LI Jun-mei, HOU Long-shu. Modeling and Analyzing on the Electric Heating Cable System for Deicing and Melting Snow on Road Surface. Journal of Beijing University of Technology, Vol.34, No.12, 1298-1303, 2008.

[4] HOU Zuo-fu, LI Zhuo-qiu, HU Sheng-liang. Research on electrical resistance variations of carbon fiber electrically conductive concrete for deicing or snow melting. Concrete, Vol.3, No.173, 3-4, 2004.

[5] WANG Jia-bin, GAO Qi, LIU Jin-chao, CHEN Kun, LI Lin-ping. Heating Cable Technology Related Snowmelt Application of ICE on Roads. Technology & Economy in Areas of Communications, Vol.17, No.2, 88-90, 2015.

[6] Hou Zuofu. Research on Making and Application of Carbon Fiber Electrically Conductive Concrete for Deicing and Snow-melting, Wuhan, China, 2003.

[7] Zhao Hongming. Experimental Investigation on Concrete Pavement and Bridge Deck Deicing with Carbon Fiber Heating Wire. Dalian, China, 2010.

[8] ZHAO Hong-ming, WU Zhi-min, CHE Guang-jie. Interval design of carbon heating wire for pavement deicing. Concrete, Vol.245, No.3, 142-143, 2010.

[9] Che Guangjie. A Study of Applied Technology in Deicing and Melting Snow for Road Surface By Carbon-fiber Electrical Heating Wire. Dalian, China, 2008. .

[10] Hou Zuofu, Li Zhuoqiu, Yang Tangsheng. On Smart Control of Carbon Fiber Electrically Conductive Concrete for Deicing or Snow Melting. Journal of Wuhan University of Technology, Vol.29, No.1, 64-66, 2005.

[11] Luo Peng. Automatic thermal control at tunnel road deicing technology snowmelt. Xi'an, China, 2010.

[12] RAM SEY JW, HEW ETT M J Updated design guideline for snow-melting systems, Vol.105, No.1, 1055-1065, 1999.

[13] LIU Xiaobing. Development and Experimental Validation of. Simulation of Hydronic Snow Melting Systems for Bridges. Oklahoma, Russia, 2005.

[14] Lu Cui. Construction Manual for the Design of Floor Radiation Heat Supply, China Electric Power Press, Beijing, China, 2012.