Observations and monitoring of icing behavior

X. Q. FU[a,*], H. XU[a], X. LIU[b], W. T. LIAO[c]
School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China
[a]*School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China*
[b]*School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China*
[c]*School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China*

At present, there are no approaches to accurate monitoring of ice cracks which seriously affect the transportation. We develop an automatic detecting apparatus and study its feasibility and monitoring principles. It is demonstrated that such detecting apparatus is able to monitor the change in ice crack width automatically and provide reliable and stable data through test results. Although this apparatus requires further improvements to better adapt to harsh the environment, the testing results showed that the data were reliable and stable for the analysis of icing behavior.

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1. Introduction

Sea ice is a common natural phenomenon in the polar and sub-polar regions. Sea ice in the Polar Regions plays an important role in the global climate system, and is an indicator of global climate change [1]. In the sub-polar sea, e.g., the Bohai Sea, the Baltic Sea, etc., varied degrees of sea ice form in every winter, which significantly affect the shipping and production of oils and gases [2]. In particular, because of sea ice, means of transport such as snowmobiles are commonly used by Antarctic expedition teams from different countries to unload on the Antarctic ice. However, due to tide and wave impacts on continental margin ice expanded areas adjacent to the Antarctic continent, tidal cracks of all sizes always form on the ice surface, and any slight movement of various icebergs along the Antarctic coastline may cause a chain reaction of sea ice, resulting in ice crevasses [3]. In summer, sea ice cracks in the Antarctic generally grow wider over the time and are covered with deep snow due to blizzards there, which makes it difficult to detect a crack and judge its width through satellite photographs and visual examination, bringing severe challenges to safe unloading. Over the last 28 years of China's Antarctic expeditions, nearly all materials were transported by snowmobile on sea ice, and dangerous condition occurred many times due to ice cracks. Therefore, it is very important and urgent to implement automatic and real-time monitoring of width of ice cracks during Antarctic sea ice melting in summer for polar region investigation.

At present, sea ice monitoring mainly depends on satellite remote sensing, shipborne or airborne radar detection [4], electromagnetic induction and laser ranging [5], shipborne sonar, and so on, which realize thickness detection of middle or large sea ice [6]. With the detecting apparatus being broadly used, it is possible to understand thickness distribution and annual variation character of large-scale sea ice [7-9]. However, the apparatus cannot monitor growth and change in ice crack. For example, it can only roughly judge the position of an ice crack and can't determine its width with satellite photograph for its limited precision. The radar detection apparatus can reduce the error to the degree of centimeter, but it need to be trailed by a trailer and can't realize real-time monitoring. The manual ice-detection is a method in which one man walks on ice and detects ice cracks with a pickaxe or other tools, and manually measures the crack upon finding it. This method is original and reliable, but it cannot realize real-time detection of change in width of ice crack and is rather dangerous for survey crew, as they are in danger of falling into ice cracks at any time. Therefore, it is very important to seek a type of apparatus for automatic and real-time measurement of sea ice crack.

2. Sea ice crack width automatic detecting apparatus and its system

On the basis of participation in studying and designing the capacitive ice layer thickness automatic detecting sensor [10], the authors designed the polar sea ice crack automatic detecting apparatus and its system, against the growth and change in sea ice in the Prydz Bay, East Antarctica, where China's Antarctic Zhongshan Station is located. The apparatus consists of capacitive ice layer thickness automatic detecting sensors, a fixed spring bracket, a measuring instrument, a fastener, batteries, antennae, a power cord, etc. (See Fig. 1).

The capacitive ice crack detecting apparatus consists of three capacitive ice layer thickness detecting sensors, forming a triangular pyramid at certain angles. The fixed spring bracket is made of three hard rigid springs of 5cm in diameter, which are butt-welded into an equilateral triangle plane bracket. The ends of the three sensors are respectively fixed to the three angles of the bracket. It has two functions. One is to fix each sensor, and the other is to protect sensors with elasticity of spring when the whole detecting apparatus being squeezed by sea ice. The measuring instrument consists of a microprocessor, memory, GPS positioning module, Iridium communication module, etc. See Fig. 2 for its functional block diagram. The microprocessor, being the core of the measuring instrument, controls the detecting apparatus and reads its measured data, as well as controls the memory, GPS positioning module, Iridium communication module, etc. The primary function of the memory is to store data of the detecting apparatus. And the primary function of the GPS positioning module is to locate the installation site and its positions after drifting with sea ice. The Iridium communication module is connected with the controller, whose function is to transmit measured sea ice crack data and GPS positioning data to the domestic monitor center via satellites. The fastener is a stainless steel cylinder of 10cm in diameter and 5cm in length, on the top surface of which there are three connectors, respectively fastening the other end of each ice thickness sensor. The fastener weighs 6 kilos, whose gravity could keep the whole triangular pyramid detecting apparatus vertical to the ice surface. The batteries adopt 12 V and 30 AH low-temperature lead acid batteries, which can supply power for the apparatus normal operation more than 400 days below -40 ℃. The antennae adopt the BDS9602 Iridium build-in GPS antenna and data transmission antenna. The power cord is a line of three-core plastic sheathed cable.

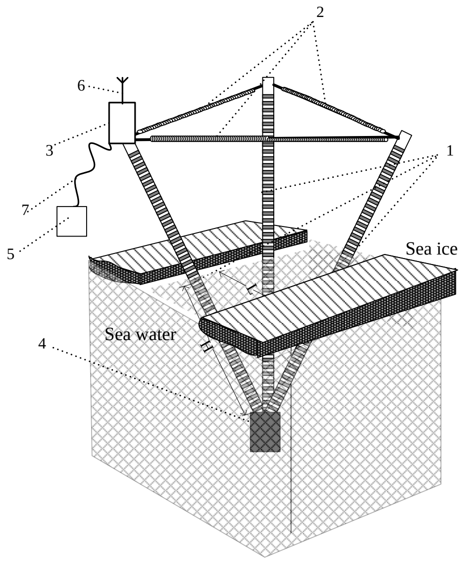

Fig. 1. Schematic diagram of structure and measurement of polar region sea ice crack width detecting apparatus 1. Capacitive ice layer thickness automatic detecting sensor; 2. Fixed spring bracket; 3. Measuring instrument; 4. Fastener; 5. Batteries; 6. Antenna; 7. Power cord.

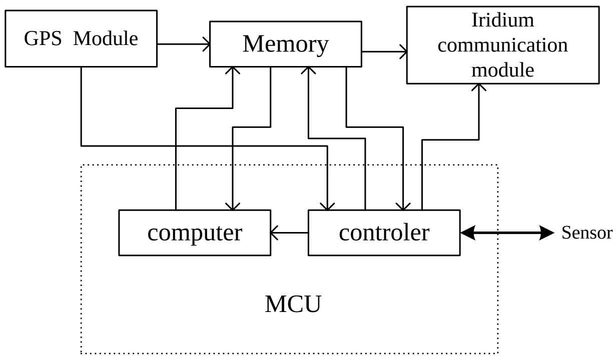

Fig. 2. Schematic diagram of measuring instrument.

The capacitive ice layer thickness detecting sensor, as indicated in Fig. 3, is mainly composed of a multi-electrode uniplanar capacitance sensor [11], connecting wire and epoxy sealing and insulation materials. The basic principle of detecting ice layer thickness is that: install the sensor vertical to the ice surface, with capacitor electrodes of 6mm in width uniformly set on its surface, where each interval is 4mm. As each electrode would respond differently to different mediums around, it is possible to obtain ice layer thickness by calculating the number of electrodes in ice.

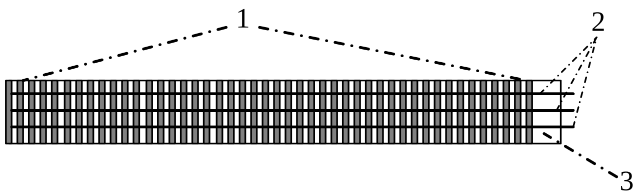

Fig. 3. Schematic diagram of capacitive ice layer thickness detecting sensor 1. Capacitor electrode; 2.Connecting wire; 3. Epoxy insulation materials.

3. Measuring method for polar region sea ice crack width

3.1 Installation of measuring apparatus

A proper observing point shall be selected prior to installation, and sea ice observation belongs to the fixed-point observation [12]. As an ice crack tends to become wider during its development, the crack originally being the widest would keep the widest. Thus, the selection condition of observing point is to select the point where the actual crack is the widest originally.

As shown in Fig. 1, vertically stick the whole triangular pyramid apparatus in an ice crack, with the fastener as bottom, to keep the plane that three spring brackets form parallel to the ice surface. Dig a hole on site and bury the batteries with snow, to keep a certain temperature.

3.2 Monitoring method for sea ice crack

Refer to Fig. 1. The measuring method is shown as follow:

Obtain the submersed height of each ice layer thickness sensor, H, with the capacitive ice crack detecting apparatus. As shown in Fig. 4, calculate the width of ice crack, L, with the microprocessor, according to the formula, where α is the included angle between $L=\sqrt{3}H\sin\frac{\alpha}{2}$ two of the three ice layer thickness sensors.

Repeat Step 1 and Step 2 periodically, obtaining results from every calculation L1, L2, L3, etc. Store the results in memory. Periodically transmit the stored data and GPS position information to domestic shore-based or shipborne receiver with the Iridium communication module.

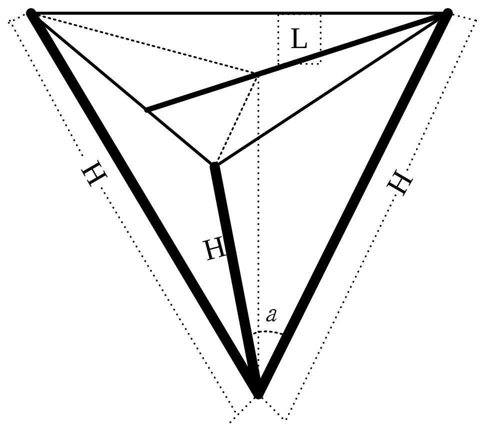

Fig. 4. Schematic diagram of measuring method for sea ice crack width.

The capacitive ice crack detecting apparatus consists of three capacitive ice layer thickness detecting sensors, which form a triangular pyramid at certain angles. In addition to capacitor electrodes in each capacitive ice layer thickness detecting sensor, there are wires to connect the three sensors, in which there're nonmetal glass rods to fasten sensors. All materials mentioned above are sealed in a stick with epoxy insulation materials.

4. Application of sea ice crack width detecting apparatus in antarctic sea ice

4.1 Application test process

During participating in the 28th Antarctic survey of China, the members of the Research Team tested the ice crack width automatic detecting apparatus on the ice near China's Antarctic Zhongshan Station on January 1st, 2012. The specific location of the apparatus is S (69° 21'53"S, 76° 22'32"E). The figure shows Xie He Peninsula where Zhongshan Station is located and the detecting apparatus installation point S (red dot in the figure). The detecting apparatus was installed according to the methods shown in the figure. Data were transmitted wirelessly or stored in a Secure Digital memory card (SD card). The wireless communication mode was only tested on site, while most of the data were obtained from a SD card.

January 1 to 22 of 2012 around Zhongshan Station are in summer in East Antarctica, when the temperature generally kept between -10℃ and -5℃, with the daily average temperature changes shown in Fig. 5. According to the figure, the daily average temperature generally remained between -1℃ and 2℃, and was rising gradually. As a result, the sea ice gradually melted away, making ice cracks wider gradually.

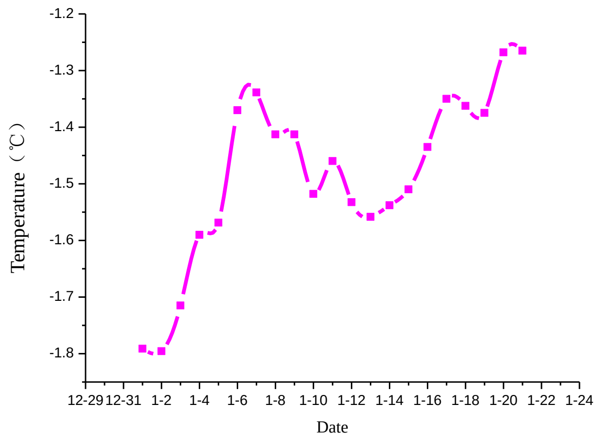

Fig. 5. Average temperature change curve, Jan. 1 - 22, Zhongshan Station.

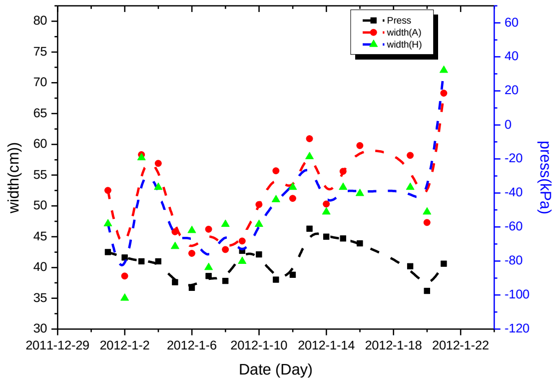

Fig. 6. Sea ice crack width & sea water pressure daily change curves, Jan.1 – 22.

Fig. 6 shows sea ice crack width and sea water pressure daily change curves between Jan.1 to 22 of 2012, where the curve width (A) is automatic monitoring data and width (H) is width change data observed manually. Not only is the sea ice crack change related to temperature, melting rate, sea ice movement, etc., but it is also related to the change of tide. So on-site researchers also collected tide level data in Na La Xia Wan at Zhongshan Station. The tide level data at Zhongshan Station were converted from sea water pressure data (as the black curve Press shows in Fig. 8) of a fixed point 5m below sea level. As can be seen from Fig. 6, there're some variations between the automatic detecting data and manual observation data of change in ice crack width, but they're in the same tendency. It is also indicated that daily change in ice crack is obviously influenced by tidal fluctuation from Fig. 6. Generally, the crack become wider when the pressure at the fixed point increases (i.e. high tide), and vice versa, but the relationship is not linear. Until January 22, the ice crack has reached 78cm at the widest point, so on-site researchers retrieved the detection apparatus and terminated the experiment, to prevent the apparatus from falling into the sea.

4.2 Problems

During the tests, due to the tough environment of the Antarctic, some problems occurred, causing measurement errors. Firstly, the triangular pyramid formed by three capacitive ice layer thickness detecting sensors inclined during monitoring, resulting in inconsistency of water level detected by each sensor and errors in ice crack width calculation. Secondly, one of the three sensors undergone a certain degree of bending deformation due to squeeze of sea ice movement, but the degree of curvature is less than 3° , resulting in a small error in measured width. Thirdly, blizzards for four consecutive days between January 8 and 11 covered the whole apparatus with snow, and there's melted water attaching to the surface of capacitive sensor after it cleared up on January 12, resulting in a big error in measurement.

5. Conclusions

In general, the developed detecting apparatus is able to monitor the change in ice crack width automatically and provide reliable and stable data through test results at Zhongshan Station. Nevertheless, to better adapt to harsh the environment of the Antarctic, this apparatus requires further improvements in the following areas. First, the detecting apparatus will be in cone-shaped and smoother, in order to reduce its inclination during detection. Second, solar panels will be installed on the top of the apparatus to charge compact accumulator batteries, in order not to bury the power supply under snow and wire it to the measuring apparatus. Third, the insulating property of the surface of capacitive sensor will be improved, in order to reduce the measurement errors due to melted water.

Acknowledgments

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*Corresponding author: hyqgxu@126.com