ULTRASONIC WIND SENSOR UNDER FREEZING CONDITIONS

Jarmo Hietanen, Tuomas Aaltio, and Mirka Moisio
Vaisala Oyj, Vanha Nurmijärventie 21, P.O.Box 26, FI-01670, Finland
+350-9-89491, jarmo.hietanen@vaisala.com

ABSTRACT

Surface wind measurements under cold climate conditions have become more and more important for meteorology and aviation community. There is a need to improve data availability and to ensure data validity. This calls for improvements to the sensor's de-icing design. The performed modifications on the de-icing design of the Vaisala Ultrasonic Wind Sensor WMT700 are briefly introduced here. The main modification was the integrated sensor body heater. Also the arm heaters were extended to overlap the transducer stack heaters. As a result, the heating power was increased from 150 W to 250 W. The modifications were tested under freezing rain conditions. The used test profiles were: A) the rain fall of 25 mm with air flow of 9 m/s at -6 Celsius degrees, and B) the rain fall of 12 mm with air flow of 20 m/s at -7 Celsius degrees. It was found out that the WMT700 sensor was operative throughout these tests.

INTRODUCTION

Meteorological community, aviation and traffic authorities, and energy industry apply high quality, professional wind sensors from operative weather observation network to industrial installation. The World Meteorological Organization, WMO, has set guidelines for surface weather observations [1]. Very often other organizations, like ICAO [2], have adopted WMO guidelines directly or with minor modifications, which further emphasize the role of the WMO. The energy sector follows IEC standards and other industrial practices [3-4]. The measurement performance guidelines and related sensor recommendations are updated from time to time to have better match to the desired measurement needs. For instance, maintenance instructions and recommendations are currently under discussion [5].

There is also a demand to operate professional wind sensors under freezing conditions. Freezing conditions are occurring on various climates. According to Köpper-Geiger climate classification, freezing conditions are discovered on Meso-thermal (C), Micro-thermal (D), and Polar (E) climates [6]. The practical consequences of a freezing condition vary significantly depending on where the freezing event takes place, how severe and long lasting an event is, and what application is considered. There are also such locations under certain freezing conditions where the commercial wind sensor has challenges to meet the requested measurement accuracy or it can even face measurement black-out for a certain period. This kind of a location could be found, for instance, on mountain areas or on Artic areas.

To maintain reliable wind readings with high data availability in cold climate installations, the wind sensor has to be equipped with a sufficient de-icing system. The essential aspects of the de-icing system are heat generation and associate sensor internal control logic. The wind sensor development emphasizes not only the implementation of the sensor de-icing system, but also testing methods and tools [7]. In this paper, freezing conditions and icing processes are discussed. Practical test methods are presented. Further, de-icing system and related performance of the Ultrasonic Wind Sensor WMT700 under the laboratory conditions is presented.

FREEZING

A freezing storm can cause significant impact on society. On December 23rd 2013, the snow accumulation of 0.3 m with the high winds of 40 m/s was expected during an event in Quebec, Canada. This ice storm cut down electricity from a quarter of a million inhabitants of Toronto and more than 300 flights were cancelled [8]. On the other hand, on mounting areas, where wide-ranging settlement is typically missing, it is possible to receive snow accumulation of 1.5 m over a weekend or ice accumulation of 0.2 m in an hour. The likelihood of these events increases when moving towards Micro-thermal and Polar climate zones and ascending on high mountain areas.

When temperature drops to around zero Celsius degree, liquid precipitation transforms to snow fall. The actual transforming process from rain fall to snow fall is physically complicated. On structures this effect could be approached with attached mass, which needs to be melted. However, icing on a structure is somewhat more complicated, since initial structure condition matters as well. Ice formation occurs when rain falls on a surface cooled below 0 °C, or when super-cooled raindrops freeze on a surface at impact. In addition, the parameters like air temperature, wind velocity, diameter of super-cooled water droplets, and liquid water content affect ice formation. Table 1 presents the standard draft of the IEC that provides the categorization for ice formation [9].

On the other hand, event duration and total rainfall intensity should be considered as well. For instance, an intense event of a very short duration can produce a limited amount of icing and thus its effect on society and various operations might be relatively mild. Respectively, a mild icing event of a very long duration can cause a severe impact on operations. The worst case is a long lasting icing event with high ice accumulation. Events causing clear ice are peculiarly challenging, because of availability of free water is high per unit volume, low temperature enables freezing, ice adhesion to structure is strong, and high wind speed condition removes heat easily away from the structure. The duration of these events is typically relatively short, while conditions of ice forming directly from cloud droplets may last weeks. Table 2 shows typical droplet characteristics from condensation nucleus to typical rain. Droplet number in a unit volume varies depending on drop size and rainfall intensity. [10-11]

Table 1. Icing events. [9].

Event	Description
Air hoar	Air hoar is formed when moist air contacts a surface cooled below 0 °C and sublimes on it. Air hoar usually forms when wind velocity is low. It consists of needle-like crystals and its adhesion to the surface is weak.
Rime	Rime is formed as a result of repeated impinging and freezing of super-cooled water droplets carried by the wind against an object. It has a very characteristic appearance of "shrimp tails" because the points where it attaches to an object are small and grow windward. Its color is white and it has a granular structure. Rime can occur simultaneously with snow causing a huge covering of snow on a suitable object.
Clear ice	Clear ice is formed when super-cooled raindrops freeze on a surface. It is hard and either opaque or transparent. It can form a layer-like structure of opaque and transparent layers with small air bubbles inside the structure. Clear ice has no particular visible structure. It is compact, its density is high and its adhesion force is strong. Clear ice is formed when the temperature is low and wind velocity is high.
Glaze ice	Glaze ice is formed when super-cooled raindrops fall on a surface and a water film is formed before freezing. Its density is high as well as its adhesion, and it has no air bubbles.

Table 2. Droplet sizes from condensation nucleus to rain drop. [10]

Droplet	Radius in microns	Number per liter	Terminal velocity [cm/s]
Condensation nucleus	0.1	10^6	0.0001
Cloud droplet	10	10^6	1
Large cloud droplet	50	10^3	27
Conventional borderline between cloud and rain droplets	100		70
Typical rain drop	1000	1	650

TEST PROCEDURES

The test procedure for freezing conditions should be adjusted so that it introduces significant stress to the unit under test, but at the very same time it should address events that are likely to occur with a normal site. Furthermore, a test should be feasible in terms of available laboratory equipment and it should be repeatable. There are two test procedures that can be used as a good benchmark [12-13]. The first one is the freezing rain test (A-procedure) utilized by the National Weather Service, USA, and the second one is the freezing rain test (B-procedure) applied by Non-Fed FAA, USA.

The A-procedure has 25 mm ice accumulation with air flow of 9 m/s. To ensure sub-zero temperature of all structures, the pre-condition of the test is cold soak of 3 hours with temperature lower than -17 Celsius degrees. Then the climate cabinet temperature is raised to -6 Celsius degrees. Icing starts by spraying pre-cooled water with wind. Ice accumulation on non-heated structures is adjusted to be 25 mm. After ice accretion of 25 mm is obtained, the water spray is shut off and the UUT exposed to the specified wind for a minimum of 30 minutes. Figure 1 presents the procedure. Figure 2 shows the test equipment inside climate cabinet.

In this test, the unit under test, UUT, should be mounted in the normal assembly position in the test chamber. The UUT is oriented to the worst-case exposure to the wind. The UUT is set operative during the test procedure. Pre-test data should be obtained in standard ambient temperature to ensure that the UUT is in order prior the test. For the operational test condition, the UUT shall be operated throughout the test. Appropriate performance test data is collected. The accuracy of the wind measurement is allowed to deteriorate during icing conditions. However, the UUT is not allowed to be damaged the ice load and the device should be fully operative within 10 minutes after the test when the wind and rain has stopped.

The B-procedure has 12 mm ice accumulation with wind of 20 m/s. Otherwise, the B-procedure follows the A-procedure.

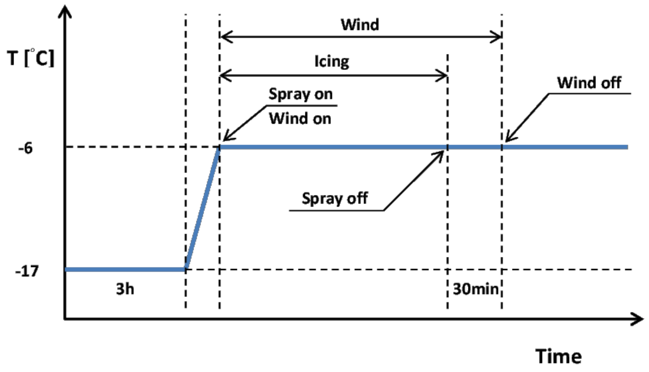

Figure 1. Test profile. 1st phase is cold soak period, 2nd phase is icing period with icing and wind, 3rd phase is wind period.

Figure 2. Test set-up includes water tank (blue), radial blower, air channel, water spraying nozzles, and UUT inside climate cabinet.

Table 3. Freezing rain test conditions.

Parameter	A-procedure (NWS)	B-procedure (Non-Fed FAA)
Airflow speed [m/s]	9	20
Flow condition	Turbulent	Turbulent
Ambient temp [deg. C]	-6	-6
Icing accumulation [mm]	25	12
Duration [min]	270	270

SENSOR PERFORMANCE

The used WMT700 sensor model has transducer, arm and body heaters and is able to measure up to 75 m/s [14-15]. To enhance de-icing two body heaters were the latest supplement to the structure [7]. The UUT was on normal measurement position and the sensor's relative North directed to the wind.

With the A-procedure ice accumulation continued for 90 minutes. The ice growth was monitored every 15 minutes. Ice formed on the structures that were facing wind and back side remained without ice cover or with very limited ice cover. The structure of ice was solid and translucent. The icing period provided the ice layer from 27 to 29 mm on non-heated structures, while on the tube of the UUT the ice layer was between 24 and 27 mm.

After the intended ice accumulation of 25 mm was achieved, the water spay was halted. However, the air flow remained on for next 30 minutes. In addition, to ice layer on sensor body and other non-heated structures facing wind, there was a small ice ball on the top of one transducer stack. This ice ball attached to the metal part on top of the equipment. The sensor arms remained ice free during this icing period. Further, the silicon surfaces producing and receiving ultrasound were without ice.

The produced wind data was monitored during the test. It was found out that the UUT was operative throughout the freezing rain test. Further it can be observed that wind speed readings were constant and aligned with the set air flow at the start of the freezing rain test. Since the wind speed values formed a relative wide belt, the flow can be concluded as turbulent. Apparently, the water content of the air did not change the quality of the wind measurement.

Figure 3. UUT after icing period. Ice layer on non-heated structure was 27 mm, while sensor tube has ice of 24 mm.

Figure 4. UUT after icing period. Translucent ice formed on surfaces facing wind.

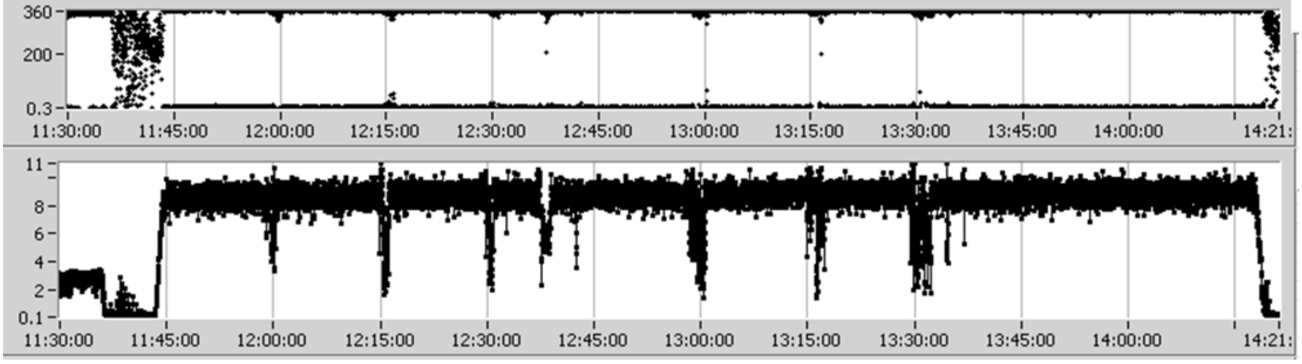

Figure 5. Measurement data from the UUT during the test period. Upper graph is wind direction and lower is wind speed. Changes on wind speed value were due to the ice thickness measurements.

With the B-procedure ice accumulation continued also for 90 minutes. The ice growth was monitored every 15 minutes. Ice formed on the structures that were facing wind and back side remained without ice cover or with very limited ice cover. Again the structure of ice was solid and translucent. The icing period provided the ice layer from 12 to 14 mm on non-heated structures, while on the tube of the UUT the ice layer was between 8 and 9 mm.

After the intended ice accumulation of 12 mm was achieved, the water spay was halted. However, the air flow remained on for next 30 minutes. In addition, to ice layer on sensor body and other non-heated structures facing wind, there was some ice on the top of one transducer stack. This ice attached to the metal part on the top of equipment. The sensor arms remained almost ice free during this icing period. Further, the silicon surfaces producing and receiving ultrasound were in practice without ice.

The produced wind data was monitored during the test. It was found out that the UUT was operative throughout the freezing rain test. Further it can be observed that wind speed readings were constant and aligned with the set air flow at the start of the freezing rain test. Since the wind speed values formed a relative wide belt, the flow can be concluded as turbulent. Apparently, the existence of the water content of the air did not change the quality of the wind measurement.

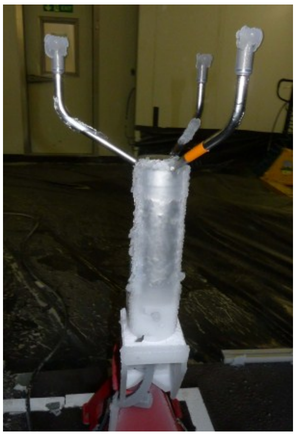

Figure 6. UUT after icing period. Ice layer on non-heated structure was 12 mm, while sensor tube has an ice cover of 8 mm.

Figure 7. UUT after icing period. Translucent ice formed on surfaces facing wind. UUT was providing data.

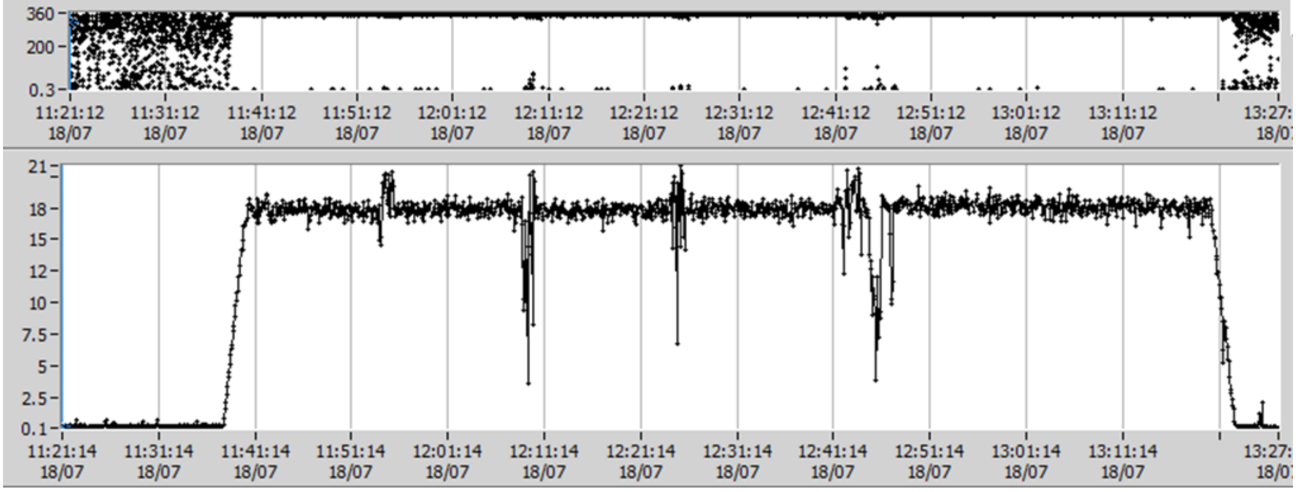

Figure 8. Measurement data from the UUT during the test period. Upper graph is wind direction and lower is wind speed. Changes on wind speed value were due to the ice thickness measurements.

CONCLUSIONS

The WMT700 Ultrasonic wind sensor was tested with two freezing rain test procedures. The A-procedure followed the NWS practice of 25 mm ice accumulation with 9 m/s wind and the B-procedure followed Non-Fed FAA procedure with 12 mm ice accumulation with 20 m/s wind.

The WMT700 was operative and provided wind speed and wind direction measurement data throughout both test procedures, even if small amount of ice was attached to the UUT transducer structures. The presence of the water content of the air flow did not change the quality of the wind measurement. Even though the WMT700 performed well and passed both of these freezing rain test procedures, the sensor can be improved further with the practice of continued improvements.

Both freezing rain test procedures are very demanding. Since the ice accumulation on transducer stacks was slightly more with the B-procedure, it could be considered as somewhat harder test.

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