# COMBINED EFFECT OF THE HEATING AND THE SUPERHYDROPHOBIC COATING ON THE DE-ICING CAPABILITY OF THE ULTRASONIC WIND SENSOR

Tomofumi Saito[1], Shigeo Kimura[1], Kengo Sato[2], Hiroshi Morikawa[3], Tetuya Kojima[3], Haruka Endo[3], Yoichi Yamagishi[1], Shigeto Mochizuki[2], and Jarmo Hietanen[4]

[1] Kanagawa Institute of Technology, 1030 Shimo-Ogino Atsugi Kanagawa, Japan

[2] National Research Institute for Earth Science and Disaster Prevention, Japan

[3] Meteorological Research Institute for Technology, Japan

[4] Vaisala Oyj, Vanha Nurmijärventie 21, P.O.Box 26, FI-01670, Finland

## ABSTRACT

In this paper combined effect of the sensor heating and the superhydrophobic coating is studied to further improve sensor performance under challenging weather conditions. The applied sample is the Ultrasonic Wind Sensor WMT700 by Vaisala Oyj. Some of the crucial improvements in this model over the previous ones are a wider heated area including the transducer arms and the top cover, and an increase in the heating power. In particular, installation of heating elements in the upper part of the arm could be expected to avoid the formation of secondary ice on the lower part of the transducer. To further assist avoidance of the icing superhydrophobic coating on the heated area for a quick removal of meltwater from the surface was applied. Preliminary tests indicated that due to the presence of the coating film there are neither negative effects on the ultrasonic transmission nor chemical damage to the transducer material. The improved wind sensors were tested in the snowing wind tunnel and their better performances in terms of ice prevention were confirmed by the absence of the formation of the ice bridge.

## INTRODUCTION

Wind measurements play an important role not only in meteorological weather observations, but also in a production of wind power, air control in airports, and traffic control on motorways and railroads. For instance, operative control of wind turbines and the movement of trains are controlled as a safety measure by judging the instant wind speed values. Hence, if there is issue with the data correctness or the data availability is too low, regulation might lead to an operative limitations or even stoppage of a wind turbine or a train line. [1-5]

An ultrasonic wind sensor was studied at the National Research Institute for Earth Science and Disaster Prevention, Shinjo Cryospheric Environment Laboratory. Inside the wind tunnel, artificial conditions of snowing were created. The results revealed formation of a primary icing followed with a secondary icing. This might lead to an ice bridge and further to an air gap between exterior transducer surface and secondary ice layer. As a consequence, there can be an effect on the data correctness or the data availability. This finding suggested that preventing the formation of an ice bridge on the transducer surface could be a promising measure for obtaining data correctness and improve data availability of the wind sensor. [6-9]

Here combined effect of the sensor heating and the superhydrophobic coating is studied to further improve sensor performance under challenging weather conditions. The Vaisala ultrasonic Wind Sensors WMT703 were used as samples [10-11]. Some of the crucial improvements in this model over the previously manufactured were a wider heated area including the transducer arms and the top cover, and an increase in the heating power. Especially, installation of heating elements in the upper part of the arm were expected to avoid the formation of secondary ice on the lower part of the transducer. To assist avoidance of the icing superhydrophobic coating on the heated area for a quick removal of meltwater from the surface was applied. Tests indicated that the coating film had neither negative effects on the ultrasonic transmission nor chemical damage to the transducer material. The improved wind sensors were tested in the snowing wind tunnel. Their better performances in terms of ice prevention were confirmed by the absence of the formation of the ice bridge.

## SNOWING WIND TUNNEL TEST SET-UP

The snowing wind tunnel inside the Cryospheric Environment Simulator of the Shinjo Cryospheric Environment Laboratory of the National Research Institute for Earth Science and Disaster Prevention was used. The aim was to study the effectiveness of the superhydrophobic coating for snow/ice prevention with the heated ultrasonic wind sensors WMT703. Two Vaisala ultrasonic wind sensors WMT703 were employed. Both sensors were equipped with body, arm, and transducer heaters. The difference between two sensors was superhydrophobic coating. One sensor was with special NTT-AT HIREC-100 painting. This superhydrophobic paint was applied to the transducers, arms, and to the top cover of the sensor, while the main body was without painting. The sensor's heaters applied peak power of 400 Watts at 24 DC Voltage.

Fig.1 shows the snowing wind tunnel test facility and coated surface of the ultrasonic wind sensor. The snowfall device was placed on the ceiling of the test section from which snowflakes were supplied into the test section. The ultrasonic wind sensor was placed on the down-stream of the snowfall device with the distance that was determined in accordance to the airflow speed in the test section in order to optimally create the snowing environment around the wind sensor. The airflow speed was varied with values of 1 m/s and 6 m/s. Table 1 presents controlled test parameters: speed of airflow [m/s], ambient temperature [C], snow flux [g/m$^2$s], snowfall intensity [mm/hour], and test duration [min]. The surface conditions were recorded using several video cameras in- and outside of the wind tunnel test section. In addition, infrared cameras were used to measure the surface temperature. The measured wind data were transferred to the personal computer via the data logger and stored in the hard disc after each test run.

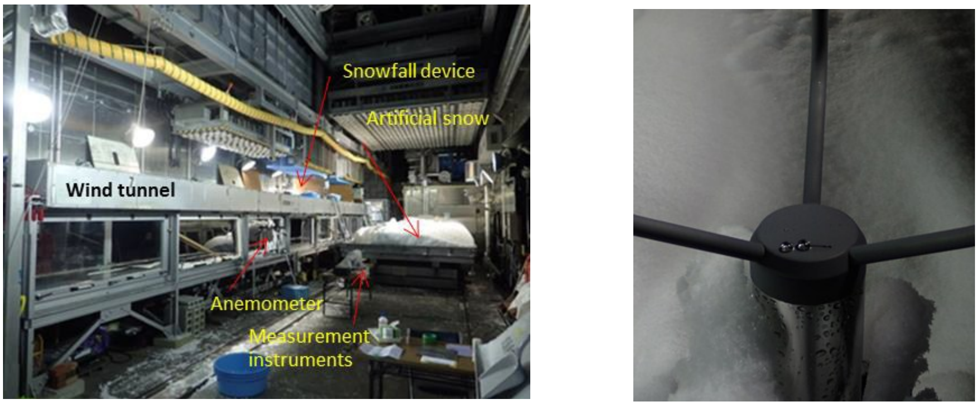

**Figure 1.** On left, test facility layout is presented. On right, the superhydrophobic coated sensor is buried after snow test run. Difference between the coated (grey) and non-coated (shiny) areas is clearly visible.

**Table 1.** Test conditions.

| Parameter | Snowing (NIED) | Snowing (NIED) |
|---|---|---|
| Airflow speed [m/s] | 1 | 6 |
| Flow condition | Laminar | Laminar |
| Ambient temp [deg. C] | -12 | -12 |
| Snow flux [g/m^2s] | 3.75 | 3.74 |
| Snowfall intensity [mm/h] | 13.5 | 13.5 |
| Duration [min] | 20 | 20 |

## RESULTS AND DISCUSSION

Apparently the transducer surfaces were clear from snow and ice throughout entire test period of 20 minutes with both standard Vaisala ultrasonic wind sensor and superhydrophobic coated Vaisala ultrasonic wind sensor. This result is valid for both test conditions of 1 m/s and 6 m/s performed at -12 degrees Celsius. On the top of the Fig. 2a it can be visually observed that there is no attached snow or ice on the standard transducer stack surface, and at the bottom the same is valid with the superhydrophobic coated transducer stack surface. When studying the measurement reading from these sensors as seen in Fig. 2b, it can be concluded that data availability is 100% with both test sensor. The very same deduction can be made with test condition of 1 m/s on Fig. 3a and 3b. Further, Fig.4 shows very clearly that sensor top is also free from snow and ice. This good performance is consequence from various improvement conducted to this sensor model based on previous research results.

When studying closely the videos, several additional effects can be observed. With flow condition of 6 m/s, only a very small amount of snowflakes are able to stick to the silicon or stainless steel or superhydrophobic surfaces. If snowflakes do stick, snowflakes melt very rapidly and turn to water due to internal heaters. The silicon and stainless steel surfaces form water droplets of different sized. These different surface materials have also different wetting properties. When superhydrophobic coating is applied, it uniforms surface properties over the silicon rubber and stainless steel surfaces and reduce the adhesion between surface and water. Then water is uniformly removed from all superhydrophobic surfaces by gravitation and aerodynamic forces.

The same phenomenon can be observed with flow condition of 1 m/s. In addition, it can be observed that some snowflakes tend to fall on the top of the uncoated transducer stack, form large droplet of meltwater, and stay there longish period because aerodynamic drag force of 1 m/s is weakish to remove them. However, when superhydrophobic coating is applied, the aerodynamic drag force produced by airflow of 1 m/s is able to take these droplets away from the surface at the very end. The benefit from all above is that with same heating energy, structure is able to stand more demanding weather condition.

This wetting process can be further theorized. Dry snowflakes attach the surface. The applied heating is able to turn dry snow to wet snow. If snow does not melt in its entirety, a thin water layer forms beneath the remaining part of snowflake. This is valid for both test conditions regardless of surface material. Primary icing is not forming. Furthermore, the applied heating prevents formation of the secondary icing as well. When the sensor heating melts snowflakes partly that are attaching the surface, then this superhydrophobic surface forms small water droplets with very high contact angle under snow. Finally, aerodynamic drag force pushes the wet snow to the side of the transducer stack and dismiss them prior additional snowflakes will attach. It was also observed that many snowflakes were directly bouncing off the superhydrophobic surface.

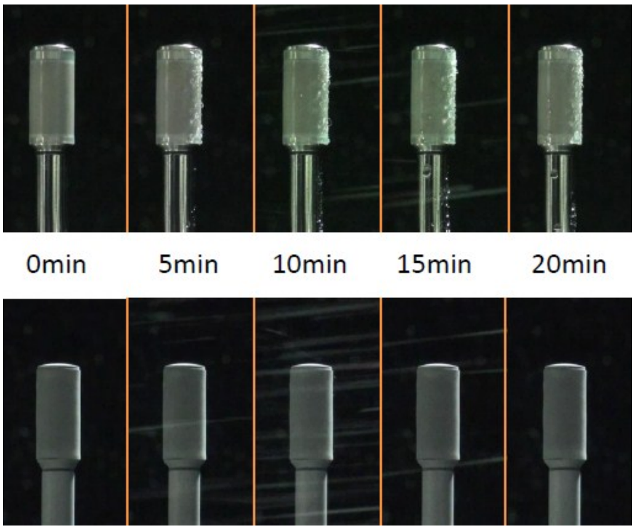

**Figure 2a.** Visual measurement results at 6 m/s. On the top visual results from standard sensor are seen at flow of 6 m/s. At the bottom visual results from coated sensor are seen at flow of 6 m/s.

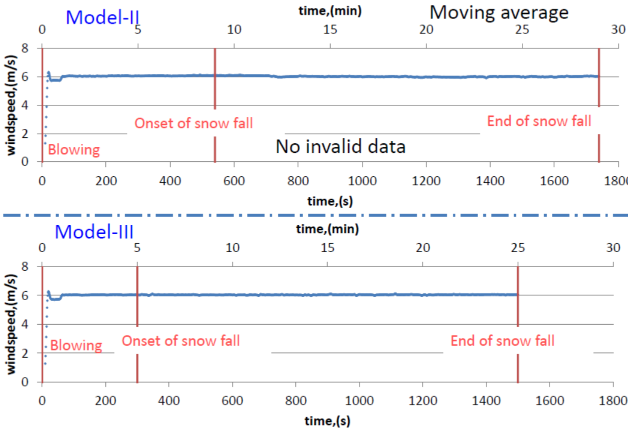

**Figure 2b.** Performance results at 6 m/s. On the top readings from standard sensor are seen at flow of 6 m/s. At the bottom readings from coated sensor are seen at flow of 6 m/s.

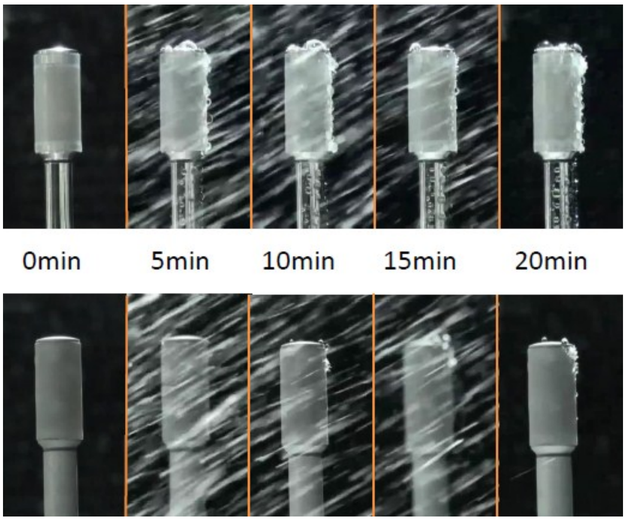

**Figure 3a.** Visual measurement results at 1 m/s. On the top visual results from standard sensor are seen at flow of 6 m/s. At the bottom visual results from coated sensor are seen at flow of 1 m/s.

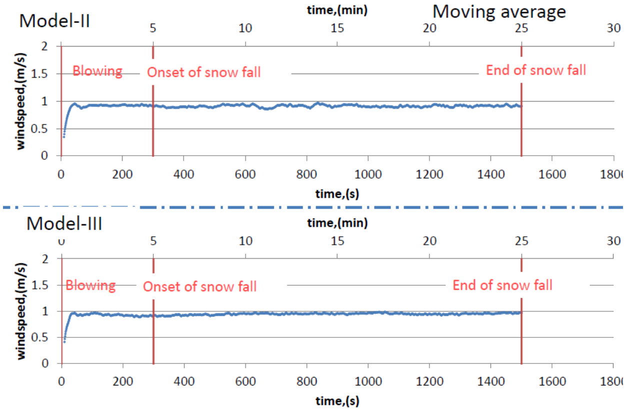

**Figure 3b.** Performance results at 1 m/s. On the top readings from standard sensor are seen at flow of 6 m/s. At the bottom readings from coated sensor are seen at flow of 1 m/s.

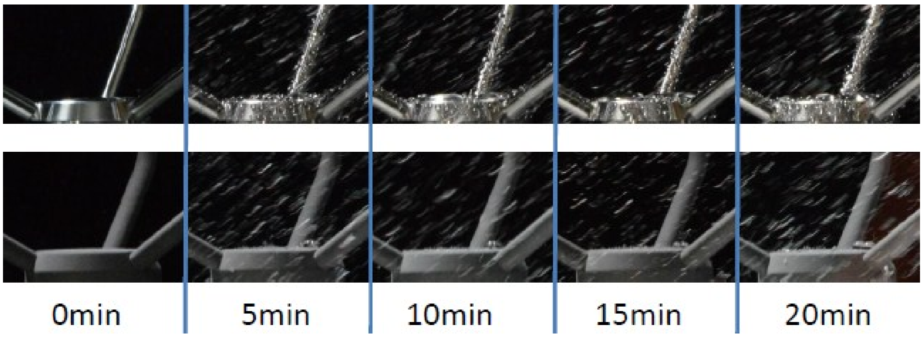

**Figure 4.** Surface condition of the standard sensor (top) and the coated sensor (bottom) are without ice and snow.

On transducer stack surface facing the wind, the wetting and melting snowflakes are collected to group due to capillary force and water surface tension. Aerodynamic force centralizes this snow lump to the front of the transducer stack. Then the gravitation will pull the snow lump slowly downwards. The snow lump continuous to melt and forms even larger water droplets having the large contact angel. At the end, the snow lump detached. It seems that with applied test parameters this occurs already at the 1/3 of the transducer stack length. When compared to the non-coated reference surface the melted snow lump was wetting more on the surface. In addition, snow lump slid all the way to the bottom of the transducer stack and detach from the corner. Thus, the total heat transfer from the superhydrophobic surface to meltwater is most likely smaller compared to the silicon and the stainless steel surfaces.

Additional observation from Fig. 4 is that if a flat surface has macroscopic structures they will behave as discontinuation barriers for sliding or rolling water droplets. At certain condition, this kind of fluid structure interaction could form a seed for initial freezing. Thus from design point of view, it is recommended to avoid unnecessary grooves on surfaces.

As concluding remarks, it can be stated that the primary findings obtained by the previously conducted research was that an ice-bridge with an air gap formed on the heated transducer stack surfaces of the wind sensor due to the secondary icing process in snowing conditions, may be the main cause of invalid and missing data. Prevention of freezing meltwater on the transducer stack surface or acceleration of removal of liquid water from it can be the best way for ensuring stable measurement. Modification of the ultrasonic wind sensor by extending the heated area leaded to avoidance of refreezing of meltwater. Further, metamorphosing the surface into being superhydrophobic with extended heating area leads to quick removal of water from the surfaces. The heat transfer from the superhydrophobic surface to meltwater is presuamble smaller due to smaller droplet contact area and faster droplet removal process compared to the silicon and the stainless steel surfaces. Snowing wind tunnel tests verified that both modifications work well and prevent icing and snow accumulation on the sensor. In particular, coating achieves its water repellency. For the future, the durability of superhydrophobic paint has to be evaluated by field tests throughout winter where the coated surface is exposed to the harsh icing and snowing conditions.

## ACKNOWLEDGEMENTS

This research was supported by the grants from the Solar Energy Research and Development Center of Kanagawa Institute of technology. Special thanks go to Mr. Motozou Ohkawa of the National Research Institute for Earth Science and Disaster Prevention for his considerable contribution to the snowing wind tunnel test.

## REFERENCES

[1] Burton T., Sharpe D., Jenkins N., and Bossanyi E. (2001) Wind energy handbook. Willey & Sons Ltd. New York.191-194, 471-509.

[2] IEC 61400-12-1 Draft (2011) *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*. IEC-TC88 Maintenance Team MT12-1. September 2011.

[3] DeFelice T.P. (1998) *An introduction to meteorological instrumentation and measurement*. Prentice Hall Inc. New Jersey. 83-105.

[4] WMO (2008) *Guide to Meteorological Instruments and Methods of* Observation. World Meteorological Organization. WMO-No. 8. Edition 7. Annex 1.B. p I.-19-24.

[5] ICAO (2007) *Meteorological Service for International Air Navigation*. International Civil Aviation Organization. Annex 3. Edition 16. ATT A-1.

[6] Kimura S. Sakabe A., Sato T., and Yamagishi Y. (2008) *Icephobic coating for prevention of secondary icing*. WinterWind 2008. Nörrköping, Sweden. P10.

[7] Kimura S., Yamagishi Y., Morikawa H., Kojima T., Sato T., Aaltio T., Valo H., and Hietanen J. *De-icing testing and development of ultrasonic wind sensor for cold climate.* WinterWind-2013, Östersund, Sweden. February 12th-14th (2013). PP-06.

[8] Hietanen J., Aaltio T., and Moisio M. *Ultrasonic wind sensor under freezing conditions*. TECO-2014, St. Petersburg, Russian Federation. July 7th-9th (2014). P1-19.

[9] Kimura S, Sato K., Morikawa H., Hietanen J., Yamagishi Y., and Kojima T. *Effect of icephobic coating on ice protection of ultrasonic anemometer with stack-type transducers.* IWAIS 2015, Uppsala, Sweden. June 28th-July 3rd (2015). P20.

[10] Hietanen J. (2010). *New standard ultrasonic wind sensor platform*. TECO. Helsinki, Finland. August 30th - September 1st 2010. P1-19.

[11] Wilson N., Paldanius J., and Hietanen J. (2012) *Practical applications of ultrasonic wind sensors for resource assessment*. EWEA. Copenhagen, Denmark. April 16th - 19th 2012. PO.90.