Determination of the actual ice mass on wind turbine blades

Measurements and methods for avoiding excessive icing loads and threads

Dr. Daniel Brenner
Head of Monitoring
Bosch Rexroth Monitoring Systems GmbH

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Rexroth
Bosch Group

Ice throw

-> heavy impact on drive train due to change of moment of inertia

Daniel.Brenner@boschrexroth.de

Typical Ice Formation: On leading edge

Daniel.Brenner@boschrexroth.de

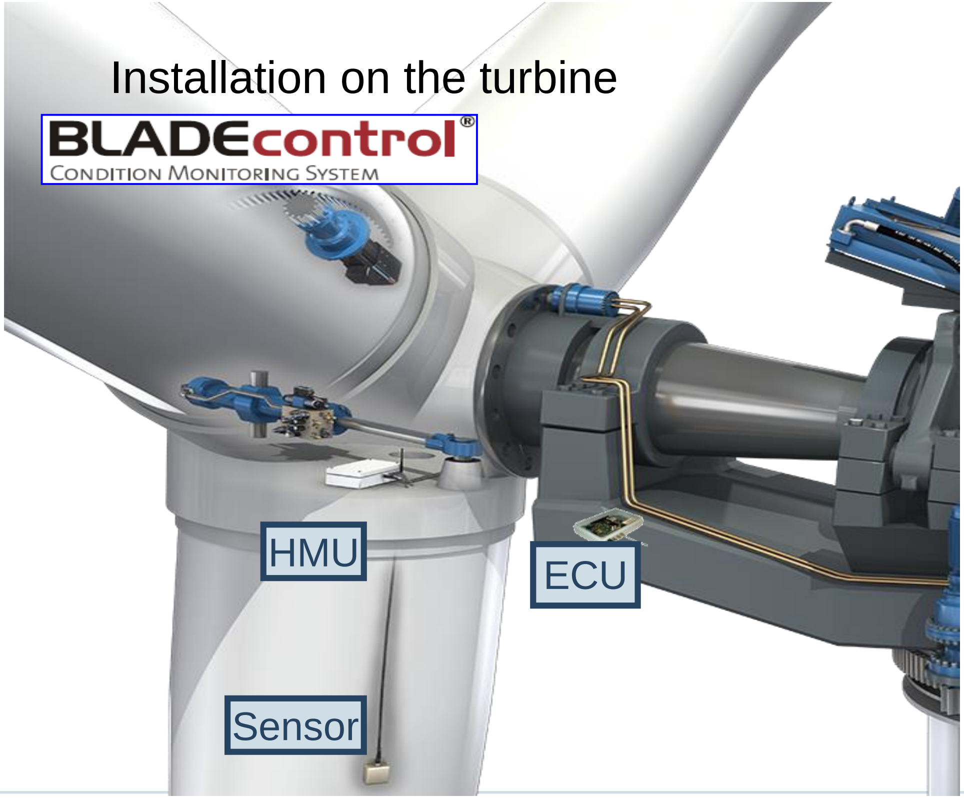
Typical Ice Formation: On leading edge

Ice formation with high density

Ice throw critical at a thickness of about 2 cm

Daniel.Brenner@boschrexroth.de

Measurement of blade vibration with accelerometers

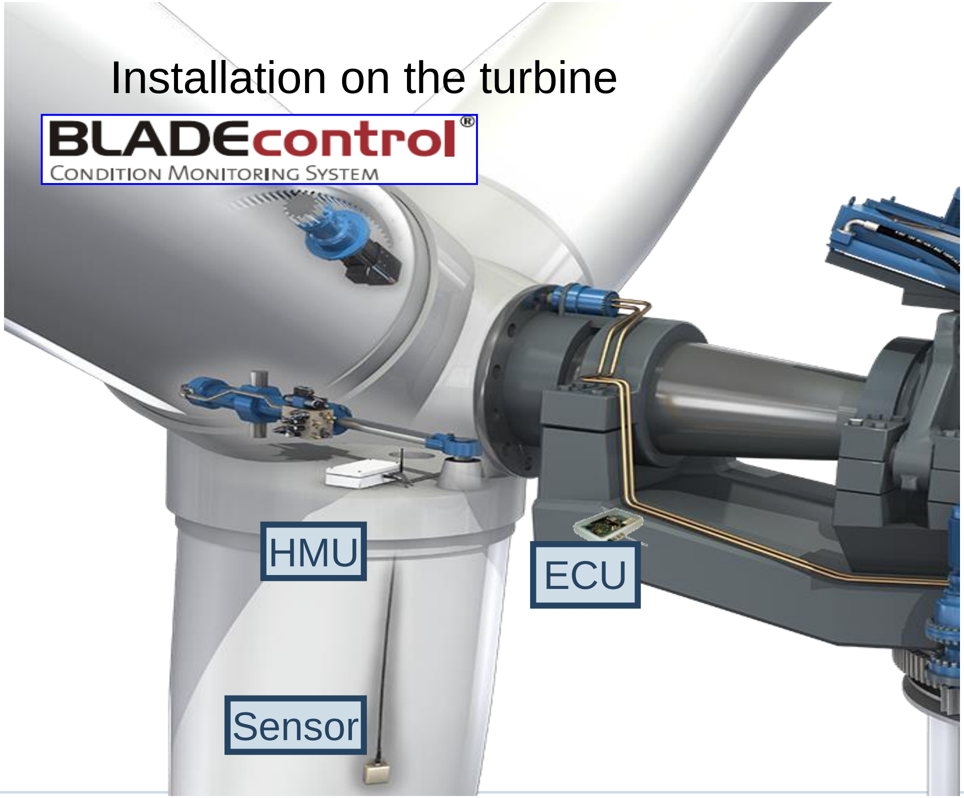


- Precise detection of icing for automated turbine shutdown and restart

HMU = Hub Measurement Unit
ECU = Evaluation & Communication Unit

Daniel.Brenner@boschrexroth.de

Measurement of blade vibration with accelerometers



- Precise detection of icing for automated turbine shutdown and restart
- Early detection of rotor blade damages

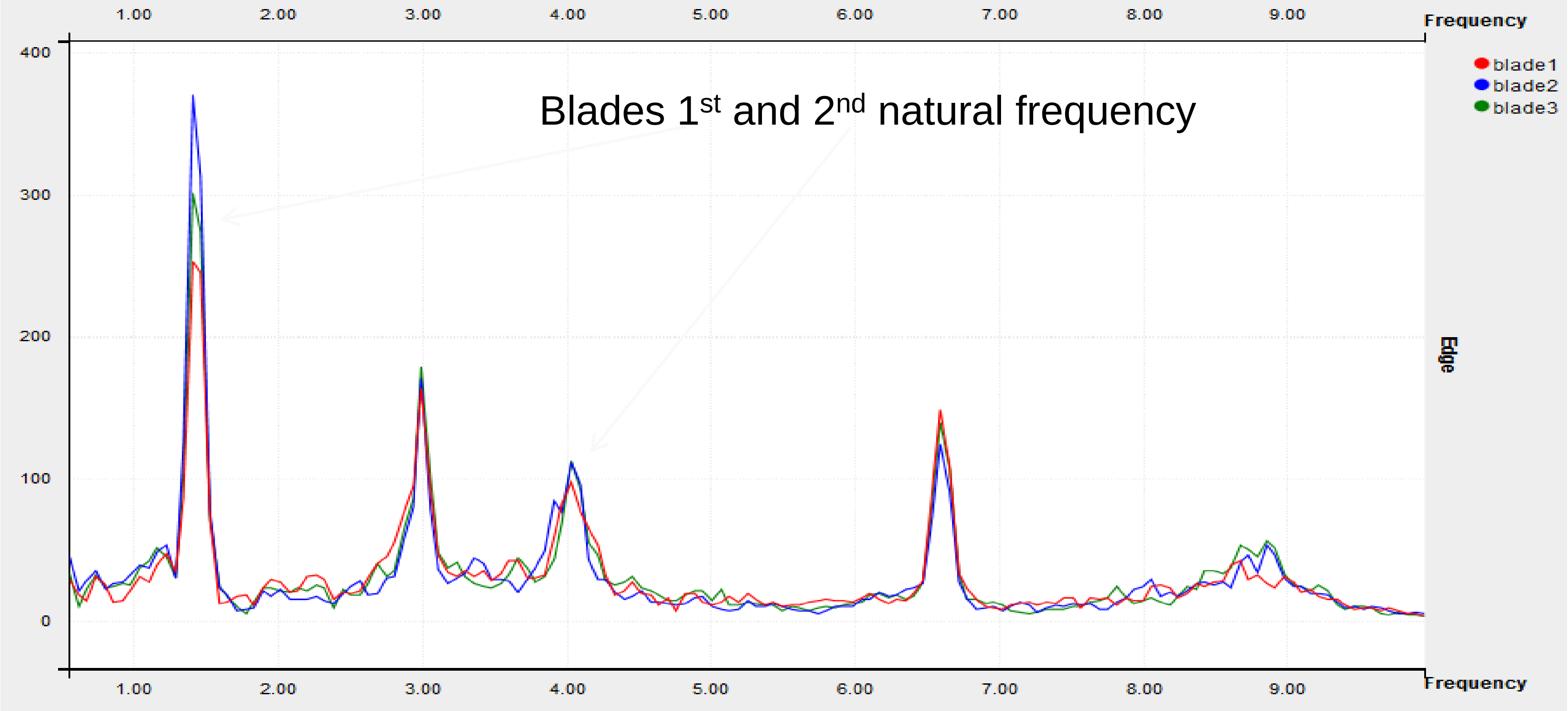
  → repair possible at relatively low costs
- Automated turbine shutdown in case of detected severe structural damages

HMU = Hub Measurement Unit
ECU = Evaluation & Communication Unit

Daniel.Brenner@boschrexroth.de

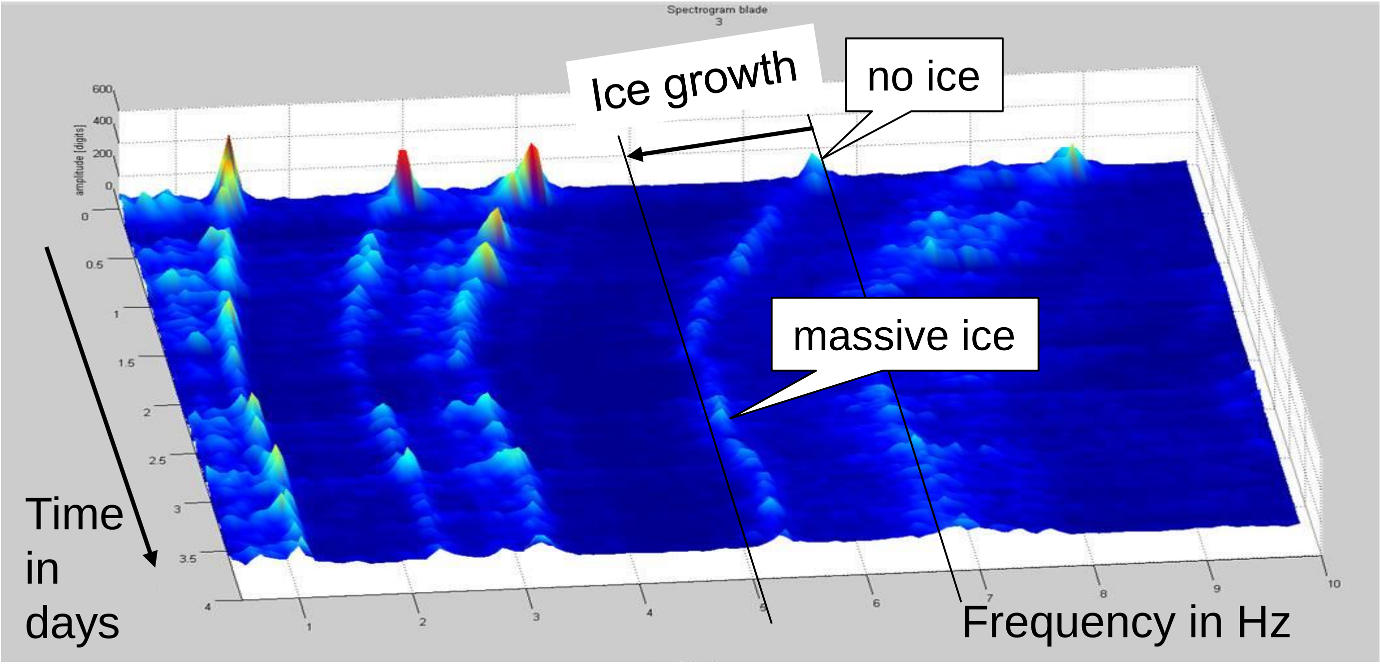
Rexroth
Bosch Group

Natural vibration at blades shown after FFT



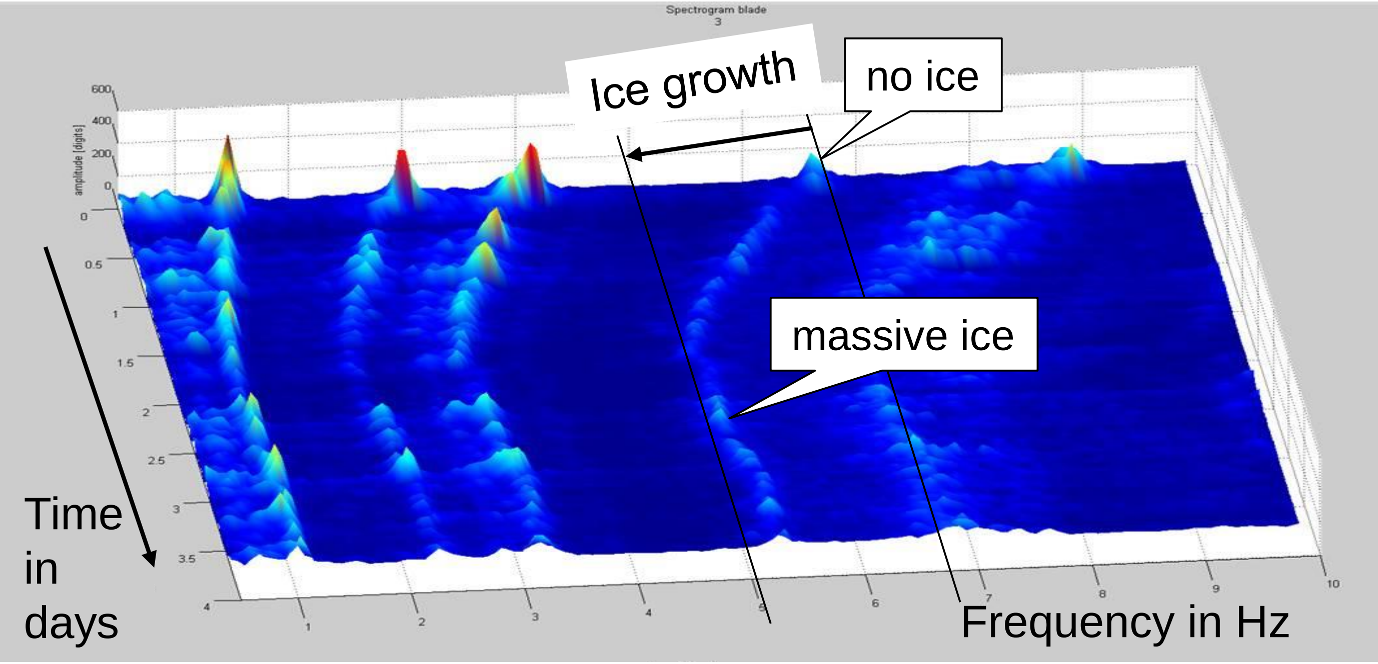
Daniel.Brenner@boschrexroth.de

Extreme icing event - spectrogram



Daniel.Brenner@boschrexroth.de

Extreme icing event - spectrogram



Icing event with over 250 kg ice per blade

- All natural oscillations decrease due to ice
  - Blades natural frequencies as well as rotor natural frequencies

Daniel.Brenner@boschrexroth.de

Determining the ice mass

conversion: frequency deviation in Hz ↔ ice mass in kg

$$m = \frac{M}{k} \cdot \frac{df}{f}$$

- M – blade mass
- m – mass of ice
- df – frequency deviation
- f – frequency without ice accretion
- k – conversion factor

Note:

Frequency deviation df has to be compensated for influences of the current operation point of the turbine

Daniel.Brenner@boschrexroth.de

Determining the ice mass

conversion: frequency deviation in Hz ↔ ice mass in kg

$$m = \frac{M}{k} \cdot \frac{df}{f}$$

- M – blade mass
- m – mass of ice
- df – frequency deviation
- f – frequency without ice accretion
- k – conversion factor

But Ice mass no indicator for risk!

-> **Ice thickness more reasonable**

Daniel.Brenner@boschrexroth.de

Determining the ice thickness

conversion: ice mass in kg $\leftrightarrow$ ice thickness in mm

- m – ice mass in kg
- l – length of the iced surface in m
- w – width of the iced surface in m
- ρ – density of ice in kg / m³
- th – ice thickness in m

$$th = \frac{m}{\rho \cdot l \cdot w}$$

Maximum ice thickness 1,5 – 2 cm until turbine shutdown necessary

Daniel.Brenner@boschrexroth.de

Example for ice mass estimation

Most critical ice accretion **only** on **outer third** of the **leading edge**

- l = 1/3 blade length
- w = 0,1 m
- th = 0,02 m
- ρ = 900 kg / m^3

$$th = \frac{m}{\rho \cdot l \cdot w}$$

Example:

- *Blade length = 45 m*
- *Maximum ice mass = 27 kg*

*-> ice mass needed for **overload estimation***

Daniel.Brenner@boschrexroth.de

Conversion frequency deviation into ice mass?

- Relation between **frequency deviation** and **ice mass** depends on **ice distribution** across the blade
- Tests on a running turbine with extra masses of lead glued to the blade fullfilled

Ice found under tower after stop from **BLADE**control

Daniel.Brenner@boschrexroth.de

Conversion frequency deviation into ice mass?

- Relation between **frequency deviation** and **ice mass** depends on **ice distribution** across the blade
- Tests on a running turbine with extra masses of lead glued to the blade fullfilled

- Ice thickness more reasonable indicator for risk assessment of Ice
- Ice at the tip is more risky than ice at the root due to higher speed
- Ice mass in kg no indicator for risk!

Ice found under tower after stop from **BLADE**control

Daniel.Brenner@boschrexroth.de