DEVELOPMENT OF AN ELECTROTHERMAL ICE PROTECTION SYSTEM FOR WIND TURBINE APPLICATIONS

IWAIS Conference

September 7th - 11th, 2009

Presenter: Dave O’Hern

Authors: Dave O’Hern, Galdemir Botura, Ken Fisher and Darren Jackson

Goodrich Corporation
Who is Goodrich?

Goodrich Aerospace Ice Detection / Protection Capability Overview

Goodrich Ice Detector Principles & Evolution

Goodrich COST-727 Involvement

Goodrich Model 0872N1 Development

Goodrich Electrothermal Heater Assembly Technology

Goodrich Heater Assembly Test Set-Up

Goodrich Heater Assembly Testing Results

Goodrich Heater Assembly Testing Conclusion

Goodrich Heater Assembly Next Steps
Goodrich Ice Detection / Protection
Centers of Excellence

Burnsville, MN
877 employees
243,000 sq. ft.

Eagan, MN
268 employees
64,000 sq. ft.

Union, WV
330 employees
140,000 sq. ft.

Uniontown, OH
99 employees
48,000 sq. ft.
Goodrich Global Presence

Over 90 locations & 24,000 employees world-wide

Americas
United States
Canada
Mexico

Europe
United Kingdom
France
Germany
Poland

Mid. East, Asia and Australia
Australia
India
Singapore

China
Indonesia
Dubai
Goodrich Ground Based Ice History

- Goodrich (Rosemount) 40+ year history of providing high accuracy ground based sensors
  - Anemometers
  - Ice detectors
  - Freezing rain detectors

- Goodrich (De-Icing & Specialty Systems) 75+ year history of providing ice protection systems
  - Pneumatic Systems
  - Structural Composites
  - Electrothermal Systems

- Long history of working with North America Meteorological Organizations
  - NASA
  - NOAA
  - Environment Canada
  - US Air Force

- Goodrich specializes in specialty heated instruments and integrated system solutions
Ice Detection / Ice Protection Applications

- Engine Inlet
- Wing Ice Protection
- Empennage • Horizontal Stabilizer • Vertical Stabilizer • Elevator
- Rudder
- Pylon Inlet
- Ice Detector
- Ice Protection
- Main Rotor Blades
- Tail Rotor Blades
- Ice Detector
- Rotor Blade Ice Protection
- Propeller Blades

Ice Detection / Ice Protection Applications

right attitude/right approach/right alongside

www.goodrich.com

6
Goodrich is a World Market Leader in Ice Detection Systems
- Over 5,000 ice detectors produced on an annual basis

- Over 40 years In-Service Experience on over 100 aircraft and numerous wind turbines, radio towers, AWOS/ ASOS stations, etc…

- Ice Detectors certified by FAA/ EASA, Military and UL/ CSA/ CE

Goodrich Ice Detection Technology Advantages:
- Accurate Detection and low false alarms
- Solid De-icing Capabilities
- Robustness (Vibration, Temperature, EMI, etc…)
- High Reliability

Various Ice Detection Technologies Available
- Magnetostrictive (most common)
- Thermal Icing Conditions Detector
- Optical Ice Detection

Capabilities Include:
- Ice / No Ice
- Icing Rate and LWC Measurements
- Liquid Water / Ice Crystal Differentiation

Prevailing Wind

20 - 30 degrees
The Goodrich Ice Detector probe and electronics are tuned to resonate at approximately 40 KHz.

The probe is made of a magnetic material and is forced to resonate at its natural frequency by magnetostriction.

Magnetostriction is the ability of certain materials to expand or contract in the presence of a magnetic field.

As ice accretes on the probe, the resonant frequency reduces due to the added ice mass.

Reduction of the probe frequency below a predetermined threshold causes the ICE signal to be activated and the strut and probe to be deiced.
Magnetostriction Ice Accretion Cycle

ICE SIGNAL activated at approx. 0.020" threshold and remains on 40-60 seconds.

Ice Accumulation, deicing, and cool down.

1 Icing Cycle
Ice accumulation, deicing, and cool down.

Heater activation

Sensor cool down

ICE SIGNAL #1 "OFF"
Goodrich Ice Detector Evolution

0872DE Family
- Ground Turbine Engines
- Rugged Environment
- Analog I/O Interface
0872CE
0872DE

0872C3 Family
- ASOS/AWOS
- Met Stations
- Improved Detection Near 0°C
- RS-232 Digital Comm
0872C3
0872E3
0872F1

8204A Family
- Power Lines
- Roads/Bridges
- IR Optical Technology
- Differentiates Water / Ice
8204A

0871LH Family
- Wind Turbines
- Low Power Deicing
- Discrete I/O, RS-422
0871LH1
0871LP1

0872N1 Family
- Radio Towers
- Met Stations
- Wind Turbines
- Severe Environment
- Improved Deicing
- Discrete I/O, RS-422
0871CB1
0872B12
0872F1
0872N1

1967 - 0871CB1
1970’s

1966 - 0872DC
1960’s

1970 - 0872DE
1970’s

1984 - 0872B12
1980’s

1994 - 0871LH1
1995 - 0872F1
1990’s

1991 - 0872C3
1995 - 0872F1

2003 - 0871LP1
2000’s

2004 - 8204A
2009 - 0872N1

1984
1994
2004

www.goodrich.com
Goodrich has donated Model 0871LH1 ice detectors to COST-727

Model 0871LH1 was developed and designed for low power applications and light duty icing (i.e. wind turbines)

Preliminary COST-727 test results indicate:
- LH1 model detected ice well under most environments
- Some deicing problems experienced with no strut heater
- Validated the market need for a more robust ground based ice detector

Proposed Improvement / Solution
- Implement Model 0872N1 for severe environments

Goodrich intends to actively review/monitor Model 0872N1 performance and incorporate improvements as necessary during the next COST Action
Model 0872N1 Development

- Replaces Goodrich Model 0871CB1, 0872B12, and 0872J1

- Potential Applications
  - Meteorological Stations
  - Wind Turbines
  - Radio/TV Towers

- Features:
  - 2 Ice and 1 Fail Outputs
    - Capable of Driving Relays
  - Robust BIT Testing
    - Power-Up, Initiated, and Continuous
  - Full De-icing capability (both strut and sensing probe)
    - Approx. 300W power, 115 or 230 VAC versions
  - RS-422 Serial Output
    - Probe frequency, Heater and Ice/Fail activation, Failure history

- Two units provided to Meteotest for 2009-2010 winter testing

- Safety, Performance and EMI Certification testing (UL/CSA/CE) to be completed by end of 2009
Goodrich has over 40 years experience integrating electrothermal IPS technologies with various structures

- Rotor Blade Ice Shedding
- IWT Testing

Blades heating performance
What is a Heater Assembly?

- The technology behind the Goodrich Electrothermal Heater Assemblies consists of:
  - **Elastomeric**
    - Flexible heater assemblies with elastomeric insulation
  - **Metal Clad**
    - Heater assemblies insulated with plies of fiberglass/epoxy and protected with a metallic outer cladding
  - **Anti-Icers**
    - Heater Assemblies that prevent the formation of ice on a protected surface
  - **De-Icers**
    - Heater Assemblies that cyclically removes ice from a protected surface
  - **The Wind Turbine Blade Electrothermal Heater Assemblies may utilize both Ant-Icer and De-Icer technologies**
  - **Heaters can be integrated into composite structures**
Electrothermal Heater Assembly Technology

Electrothermal Heater Assembly

Samples

Cross-Section

Leading Edge Surface

Fiberglass / Carbon Fiber / Epoxy

Heating Element

Integrated Film Adhesive
Electrothermal Heater Assembly Technology

Standard Heater Element: New vs. Old Alloy Fatigue Strength

![Element Alloy Fatigue Test Data](chart.png)

- New Alloy, Old Design
- Old Alloy, Old Design
- New Alloy, DuraTherm Design
- Fit
- Fit

Cycles to Failure vs. Mean Strain (micro in/in)
Heater Assembly Test Set-Up

Icing Wind Tunnel
– Forward Looking (Spray System) View

Icing Wind Tunnel
– Side View
Simulated Wind Turbine Blade Test

- Hybrid Electrothermal System
  - De-icing and Anti-icing
  - Composite leading edge structure

- Leading Edge with 0.050” - 0.020” (1.27mm - 0.508mm) Gelcoat

- Tested at -4°F (-20°C)

IWT Heater Assembly Video
19 Seconds…
- All ice removed

2 Seconds…
- Ice shedding in small pieces

3 Seconds…
- All ice removed

Note Parting-Strip area... here on stagnation zone

Heater Assembly Testing
Heater Assembly Testing Results

- The electrothermal system produced successful icing wind tunnel test results

- Ability to Shed Ice Very Thin

- Graphite heater assembly tested for 1,000,000 temperature endurance cycles

- Electrical connections tested for extreme temperature from -200°F (-129°C) to +300°F (149°C) without degradation

- Heater Assembly reliability in order of 1 failure per 500,000 flight hours
Goodrich electrothermal heater assembly technology has been installed on various rotorcraft and engine propellers with proven performance and reliability.

Goodrich aerospace Ice Protection Systems can be converted to wind turbine applications.

Goodrich extensive experience in ice protection development provides unique capabilities to minimize project risk.
- **Internal test facilities:**
  - Icing Wind Tunnel
  - Rain Erosion Facility
  - Advanced Ice Testing methods

Goodrich provides complete integrated solutions for ground based applications.
- Ice Detection, Ice Protection and Heath Monitoring Systems
On-Going Efforts

- Development of Model 0872N1 harsh weather ice detector
- Development of cost effective Ice Protection System (Heater assemblies, controllers and wiring integration)
- Looking for the right Ice Protection System collaboration for near-term and future ground based test platforms and applications
The Goodrich Website

- For more Information
- Visit the Goodrich Website: www.goodrich.com
  - Business Segments
  - Capabilities
  - Literature
  - Product Overviews
  - Pedigree
QUESTIONS ????