Benefits of Prognostics for Power Electronics Systems

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Agenda

- Ridgetop Overview
- Prognostics and Reliability
- Solution Examples
  - Power Systems and Actuators
  - Rotary Systems (Gear Boxes)
  - Battery Management Systems
  - Intermittency Detection in cables and interconnections
- Questions
Incorporated in 2000, and headquartered in Tucson, AZ. Ridgetop Europe established in 2010 in Belgium.

Advanced Diagnostic and Prognostic solutions:

- Sentinel Suite™ Family of Diagnostic and Prognostic Analysis Solutions
- State of Health (SoH) and Remaining Useful Life (RUL) on complex electromechanical systems.
- Improved Test Program Coverage Tools
- Design and Integration Services

Strong market position with commercial and government customers in USA, Canada, Europe, and Asia
Ridgetop Accreditations

ISO9001:2008 Quality Management System

AS9100C Quality Management System

Microelectronics Trusted Supplier (Defense Microelectronics Agency)
Prognostics Background
Reliability “Bathtub Curve”

Threshold Trigger Points are selectable

Advanced Warning of Failure (RUL)
Root Cause Analysis used for Failure Modes and Effects Analysis (FMEA)
**Usage Environment**

- Usage monitoring would provide a safety benefit if actual usage is more severe than predicted (red region, $T_1$).
- Service life can be extended beyond normal replacement time if the actual usage severity is known (green region, $T_2$).

PHM enables replacement only upon evidence of need.
What is it?

- **Diagnostics** – is the process of determining the state of a component to perform its function(s).
- **Prognostics** – is predictive diagnostics which includes determining the remaining life or time span of proper operation of component.
- **Health Management** – is the capability to make appropriate decision about maintenance actions based on diagnostics/prognostics information, available resources and operational demand.

PHM turns ‘Bad Actors’ or ‘Intermittents’ into scheduled maintenance without affecting the success of the Mission.
Prognostics Supports Proactive Maintenance

Going from REACTIVE to PROACTIVE

1. Repair/Replace when Broken
2. Maintenance as Suggested by Manufacturer
3. Diagnostic of Components
4. Condition-based Maintenance (CBM)

Reactive

Proactive (Prognostics)
Prognostics Ecosystem

1. Line Replaceable Unit (LRU)
2. Communicate PHM data
3. Integrated Diagnostic/Prognostics Design Platform
4. Real-time Health & RUL
5. Identified Design Improvements

Scheduler

CBM Actions

Subsystem OEM

Address ECRs and Improve Parts

Maintenance

Minimize Inventory

Replacement Parts

Parts
Faults Occur at Multiple Levels in Systems

Ridgetop Five-level Model
Progression of Electronic Health Solutions

Component Level
- Radiation damage
- Intermittencies
- Degradation

Board Level
- IC, capacitors
- FPGA/CPU
- Solder joint intermittencies

Module Level
- CNI prognostics
- Digital boards
- Power/analog boards
- Connectors

System Level
- Embedded Sentinel Network™ with HealthVIEW™ software
- System-level state-of-health (SOH) analysis & prognostics
- Remaining useful life (RUL)
- On-board monitors
- Communicate with ground-based systems

Die Level
- Process-related
- Wear-out/radiation effects
Ridgetop’s Sentinel Suite Platform

A family of complete solutions for electronics prognostics and health management.

- **Sentinel Power™**: Monitors, analyzes, and predicts impending failure in power systems.
- **Sentinel Motion™**: Enables wireless extraction of high-resolution signatures from vibrating/rotation components.
- **Sentinel Interconnect™**: Detects interconnect degradation and intermittencies in PCBs, connectors, and 2.5/3D IC packages.
- **Sentinel IT™**: Provides efficient network health management and troubleshooting of IT networks.
Sentinel Suite Complete Solution

- Continuous sensor monitoring with analysis using proven algorithms
- Provides system-level State of Health (SoH) indication with accurate Remaining Useful Life (RUL) estimates
- Results can be integrated with existing CBM systems
Power Systems and Actuators
Building a Prognostic-Enabled System
Switch Mode Power Converter (Buck Topology)

IQbus 42v → 14v Buck Converter

closed loop switching circuit using generic modulation circuitry
includes models created by characterization tools (MOSFET, diode, magnetic)
Characterization tools can be opened from parts library tools or by double clicking on parts

Control voltage is approximated by: \( v_o = \frac{\text{duty cycle}}{\text{ramp voltage}} + \text{voffset} + \text{offset} \)
Basic Prognostic-Enabling Steps

Step 1: Characterize Device or System Failures

- Key Failure

- Pareto Ranking of Key Failures

Step 2: Extract Precursor Signatures to Failure

- Target Position vs. Rotor Position
- Following Error
- Degradation Curve

Step 3: Calculate Remaining Useful Lifetime (RUL)

- Device or System Lifetime

Designing a Prognostic Solution
Pareto Analysis

Root Cause Analysis used for Failure Modes and Effects Analysis (FMEA)

When Capacitors fail (short to GND), they also short out diodes

Customer returns

Capacitors are significant cause of power supply failures as reported here.
Objective: State of Health and RUL

- No change in capacitor value
- Capacitor begins to degrade (change in value)
- More degradation changes slope of degradation curve. RUL is reduced from original estimate.
- Initial RUL Curve
- Updated RUL Curve
- End of Useful Life

State of Health

100%

10%

Time

RUL
Helicopter Power System Application

- CBM+ applied to power systems in harsh environment
- Apache Helicopter where vibration, heat, shock all can reduce lifetime of deployed systems
- Extracts and processes eigenvalues as a metric of health
Power System Eigenvalue Extraction

- Non-invasive diagnostic and health monitor for power system applications
- Stand alone early warning approach
- Detects wear out signatures prior to any noticeable reduction in performance
- Rapid testing on-line or off-line
- Patented method
Both supplies provide regulated voltage, but one is degraded and will soon fail.
SMRT Probe™ Power System Signal Acquisition

- Shows change in system response as power devices degrade with age or stress
- Prognostic indicator is independent of noise effects
- Effective extraction of degradation signatures on highly damped and “stiff” systems
- Applicable to a wide range of power systems
Battery Management Systems
Battery and Fuel Cell Management Systems

- Various Chemistries
  - Lithium Ion
  - NiCad
  - Lead Acid
  - etc
- PEM Fuel Cells
- Control Chips for balance of plant
- Individual Cell Monitors for adjustment of charge balance
From US Navy Sources:
“Predicting NiCad cell life expectancy, especially in series-connected multi-cell battery arrays, is a major issue within embedded military applications. Current cost to replace sonar system batteries is upwards of $450,000 each time. Moreover, poor battery reliability has significant intangible impacts to MH-60R fleet readiness “

Technical Issue:
The weakest cell in the series is vulnerable to reverse bias conditions during deep discharge. Conversely, the strongest cell in the string is vulnerable to over-charging in the charge cycle. This significantly reduces cell lifetimes and reliability.

Ridgetop’s solutions:
Innovative designs that allow individual cells to be monitored for charge and discharge, and optimize each cell so as to maximize battery life and reliability, as well as reduce overall system cost.
Battery Management Systems (BMS)

- Prognostic-enabling of BMS:
  - Monitor charge and discharge profiles for individual cells
  - Read SoC (State of Charge) of individual cells or a stack of cells
  - Examine the RUL (Remaining Useful Life) of individual cells
  - Dynamically balance the stack of cells to extend lifetime
Battery Discharge Curves

Prognostic systems use this data for accurate State of Charge (SoC) and Remaining Useful Life (RUL) estimates.
Design Solution

- A special Lithium Ion Battery or Fuel Cell Stack Monitor Application Specific Integrated Circuit designed to measure individual, 0-2 VDC, cell voltages in up to a 48 cell stack. The analog cell voltages are sampled and converted to digital words with 9 bit resolution.

- Features include:
  - Single chip replaces 48 discrete cell measurement circuits
  - Rejection of common mode voltage up to 100VDC
  - Radiation hardened design
  - Integrated Prognostic cells measure cumulative radiation effects and provide early warning of impending failure
  - Supports Health Monitoring applications and more precise, closed loop designs of battery management systems (BMS)
Ridgetop Measurement and Control IC

Cell Monitor Chip

- Differential Switched Capacitor Sample and Hold
- Cell Select Switch Network
- Sampling Capacitor
- 6 to 48 Decoder Cell Selector
- Decoder Control Lines
- Non-Overlapping 4 Clock Signals
- ADC
- Digital Output Lines
- IVHM Functions:
  - RadCell FOX
  - RadCell VT
- IVHM Outputs
- Interfaced with Fuel Cell ASIC

Microcontroller

- Radiation Effects Health Monitor
- 10 bit Parallel Digital Cell Voltage Input
- Microcontroller CPU
- ADC Control
- Input Control
- Clock
Rotary Gearbox Prognostics
Helicopters suspended as gearbox fault blamed for Super Puma ditching

STV 13 May 2012 12:02 BST
The owners of a helicopter which ditched in the North Sea last week grounded more aircraft today after an early investigation revealed a fault in its gearbox.

The move comes after an initial Air Accidents Investigation Branch examination of the EC225, which went down while carrying 12 passengers and two crew, showed it suffered a crack to a gearbox shaft.

Bell OH-58 Gearbox with RotoSense™ Unit Locations

- Sun gear wireless sensor
- Pinion gear wireless sensor
- OH-58 Gearbox
Small size allows the whole system to be mounted in the shaft of the transmission
Current RotoSense System

Complete module
(other enclosures are available)

Module mounted in the shaft of the transmission
Wireless Interface

- Wireless rotation sensor inside Bell OH-58 gearbox spinning at 5,500 RPM

- Data is being logged and compared in real time between the local testbed and remotely located wireless gateway with exacting results
Sentinel Motion Extended Monitoring System
On Board and Off Board Issues

- Wireless Sensor nodes are placed in critical areas to collect both rotation and vibration data.
- Onboard Health and Usage Management System (HUMS) integrates the SoH and RUL for immediate notification.
- All data can be downloaded for CBM interactions with ground station equipment.
- Criticality of faults (Classification).
Sentinel Motion with Wi-PHM – Wind Turbines

- RotoSense sensor is installed in the gearbox of wind turbines
- The sensor will gather data on the performance of the equipment
- The data will be transmitted wirelessly to a gateway in order to be processed and analyzed

Image source: http://www.techienation.com/2008/08/14/understanding-wind-power-wind-generators-turbines/
Sentinel Motion Wind Power Application
Intermittency Detection
Intermittencies

- Over 50% of reported problems at the module level cannot be duplicated.
- Costly warranty repair cycle begins as intermittencies contribute to faults, then incorrect actions are taken for customer.
- Source of problem: Cables, solder joints and temperature-related performance variation in ICs, batteries and printed circuit boards
With present technology, reported electronic system problems in the field cannot be duplicated at the service point or in the lab

“Three/Four-letter” words (CND, NTF, RTOK)
- Could Not Duplicate (CND)
- No Trouble Found (NTF)
- Retest OK (RTOK)

50 to 80% of these CND/NTF/RTOK problem categories are reported by service personnel.

Major culprits – Solder joint intermittencies and NBTI effects in deep submicron ICs
Solder Balls, Cracks and Fractures

SJ BIST Detection Solution

SJ BIST is part of the Sentinel Interconnect product line
Prognostic Algorithms
Ridgetop developed software that takes advantage of the fact that failure modes produce predictable degradation signatures. Each input data sample is used to adapt an Fault to Failure Progression (FFP) signature definition to the data. The adapted FFP signature definition is then used to produce accurate RUL and SoH estimates that can be used to generate diagnostic and prognostic information: messages, plots, thermometers, and so on.
RingDown and ARULE*

* US PATENT 7,619,908; PATENT PENDING
Integrated Solutions
Prognostics Ecosystem

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5. Line Replaceable Unit (LRU)

Scheduler

Real-time Health & RUL

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Maintenance

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Prognostics helps augment conventional reliability based design methods.

Ridgetop has delivered innovative Sentinel Suite-based product solutions to many aerospace, industrial, and oil/gas equipment firms.

Recent examples of prognostic-enabled systems

- Power Systems
- Power EHA actuator systems
- Printed circuit boards
- Mechanical Systems
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Questions?

- Slides are available upon request. Use the GotoMeeting chat now or send an email to information@ridgetopgroup.com

- E-mail follow-up questions & comments to doug.goodman@ridgetopgroup.com

- Please fill out our brief feedback survey at https://www.surveymonkey.com/s/ZNC2H6Y

Thanks for your time and attention!