MICROWAVE BLADE TIP CLEARANCE SYSTEM: AN UPDATE

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Microwave Blade Tip Clearance System: An Update

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Overview

- Sensor Basics
- System Overview
- Laboratory Measurements
- Example Tip Clearance Data
- Example HCF Data
- Future Directions

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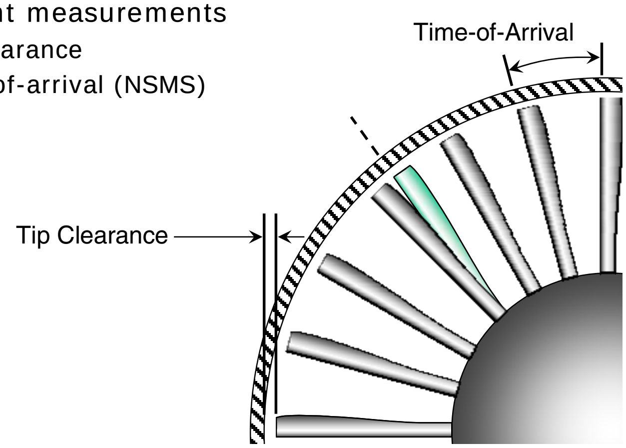
Blade Tip Sensing

- Important measurements
  - Tip clearance
  - Time-of-arrival (NSMS)



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Why Measure Blade Tips?

- In the HPT for every 1 mil improvement in clearance[1]
  - SFC decreases 0.1%
  - EGT margin increases 1°C
- Newer engines use compressor bleed air and a model to close clearances open loop
- Measuring clearances and closing the control loop can add additional efficiencies
- Tip clearance control has been identified as a key technology for future engines
- Additional benefits in prognostics, NSMS, and condition-based maintenance

[1]Wiseman, et al., "An investigation of life extending control techniques for gas turbine engines," Proceedings of the American Controls Conference, Arlington, VA, June 25-27, 2001

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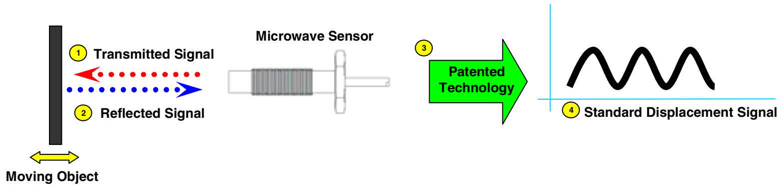
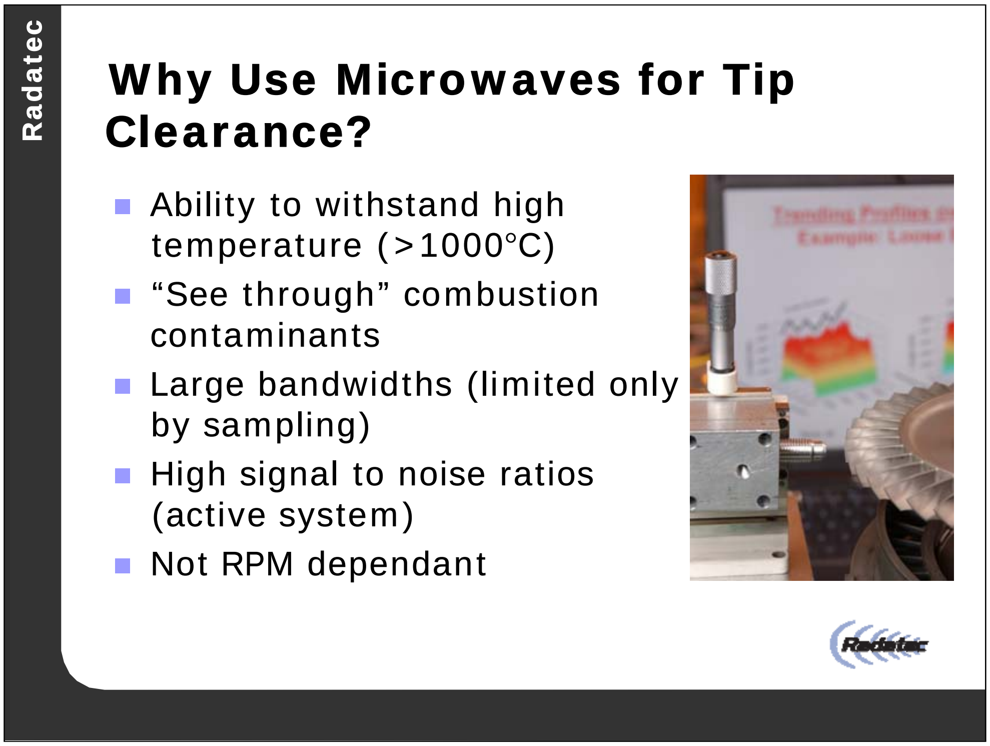
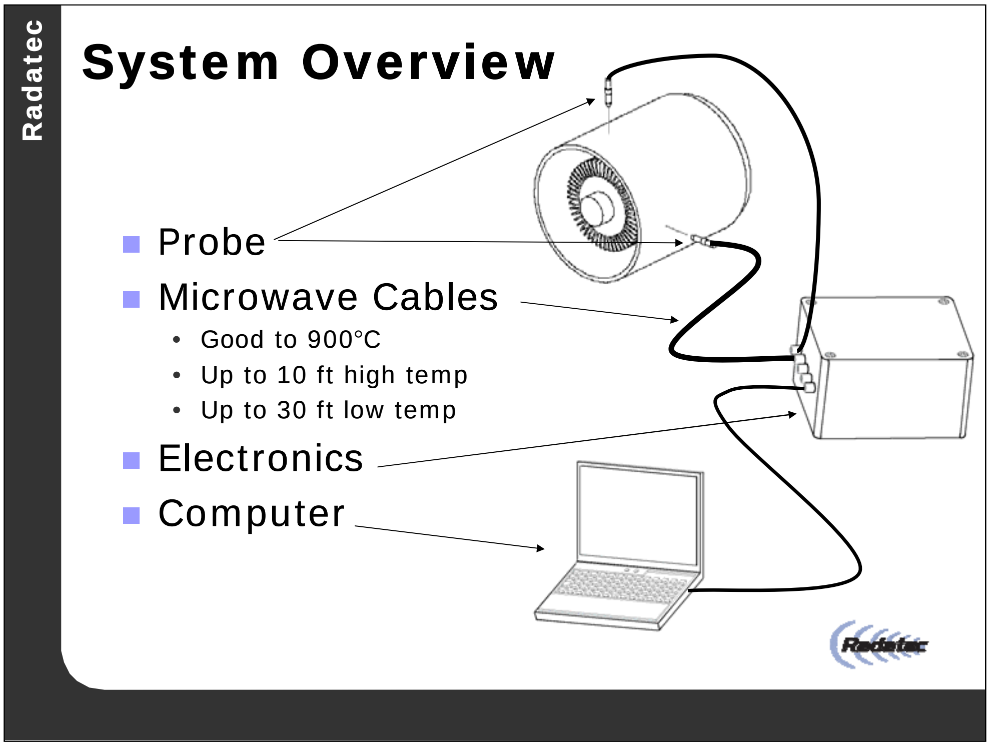
Sensor Overview



- Non-contact displacement sensor
- Phase-based microwave technique
- Measures displacement smaller than the transmitted wavelength



The microwave displacement sensor operates similar to many other non-contact displacement sensors, but tends to be more robust to environmental effects. Microwaves can penetrate through many non-metallic materials such as oil, that would give problems to other sensors. In addition, the techniques are phase-based, so the displacement measurement is somewhat independent of the metal or surface finish being examined. Because an active microwave beam is used, the sensor can take measurements at any target speed from DC on up. Other sensors based on resonant cavity techniques only give valid readings over a certain range of motion. The motion of the target encodes the information of the transmitted electromagnetic wave and the only practical limitation to bandwidth is how fast you can sample the data.



This example shows the current state of the hardware, where two probes are used to fully characterize radial motion. Right now, a computer is being used to collect the raw data and then the radar to displacement conversion as well as the data analysis is being performed off-line. One of the major efforts currently ongoing is to develop the real-time signal processing for the sensor to generate real-time displacement outputs.

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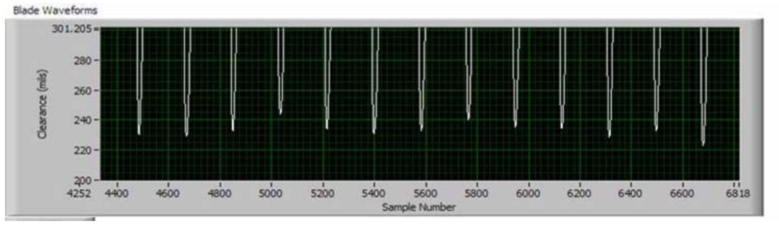
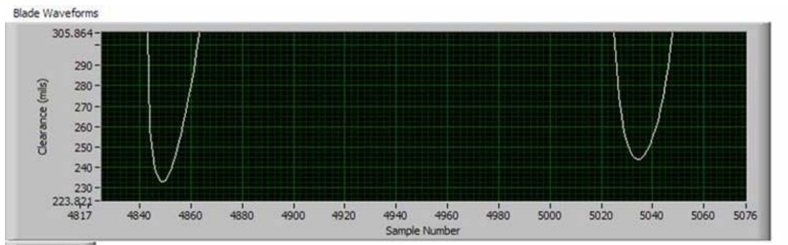
Example Waveforms





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Probes

- High temperature nickel-alloy metals
- Ceramic dielectrics

Size Doesn’t indicate Measurement Range

Probe Reliability

- Designed for 2500°F gas path
- Use compressor bleed air for active cooling
- General testing approach
  - Air furnace isothermal exposure
  - Temperature transient cycling
- Probe construction- Meggitt Safety Systems

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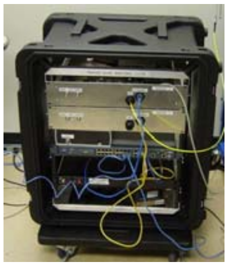
Current Prototype

- 2U, 19” rack per sensor
- Rack mount computer
- Ethernet communications



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Compact PCI Product Platform

- Now in prototype build
- CompactPCI 6U Chassis Based System
- 1 Sensor per 6U Slot

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Real Time Processing

- Field Programmable Gate Array (FPGA) runs algorithms in real time
  - Runs continuously at sample rates up to 20 MHz
  - Converts microwave signals to displacement
  - Extracts features from blade
- Able to continuously extract tip clearance and time of arrival (ToA) digitally in real time for every blade
- Clearance and ToA streamed to PC via 10/100 Mb Ethernet (UDP/IP)

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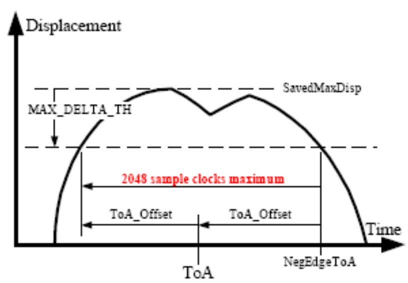
Feature Extraction

- Blade waveform is measured in distance, not voltage
- First, pick out peak of blade
- Then, go down the blade a set distance on both the pressure and suction side of the waveform (distance to go down is a parameter that can be changed)
- Notate time of arrival and time of departure



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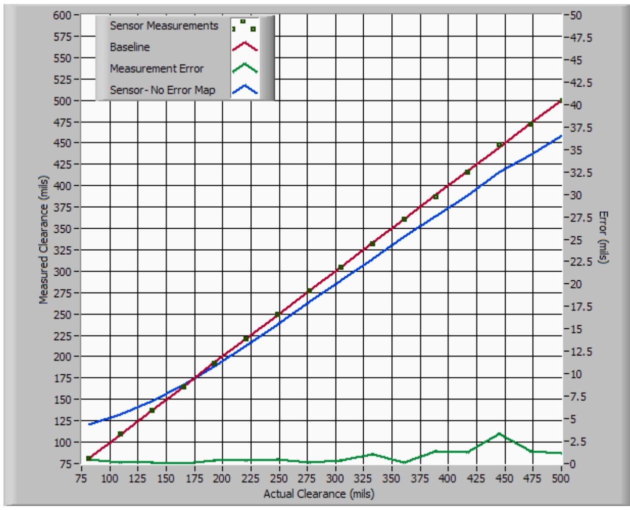
Laboratory Tests- Turbine Blade Linearity



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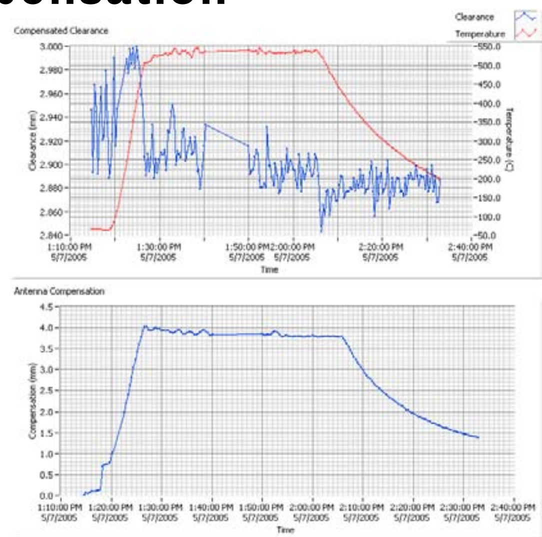
Laboratory Tests- Cable Compensation



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Sensor Specifications

- **Sensor Bandwidth-** 10 MHz (20 MHz sampling)
  - Same waveforms from zero RPM to full speed
- **Resolution-** 0.5 mils
- **Linearity-** ~1% of full scale range, target dependent
- **Sample Rate-** 20 MHz
- **Onboard Memory-** 32 MB
- **Probe Temperature-** >1800°F
- **Microwave Cabling-** 0.142” cable up to 30’
- **Digital Data Outputs-** Time of arrival, tip clearance
- **Analog Outputs (10 MHz bandwidth)-**
  - Blade waveforms
  - Voltage proportional to TOA
  - Voltage proportional to clearance
- **Sensor to PC Communications-** 10/100 Ethernet, UDP/IP

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Power Systems Testing

- Large frame power systems engine
- Second stage turbine
- Gas paths of 2000°F
- Active cooling design

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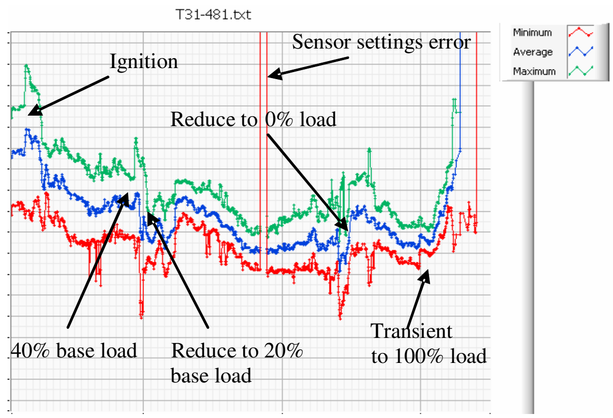
Example Clearance Plot



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High Cycle Fatigue (HCF)

- Spin pit test
- Fan blade monitoring
- Seeded defect in blade
- Oil jet excitation to induce stress

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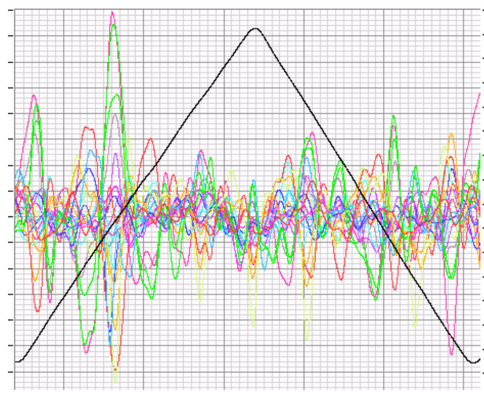
Example Resonance



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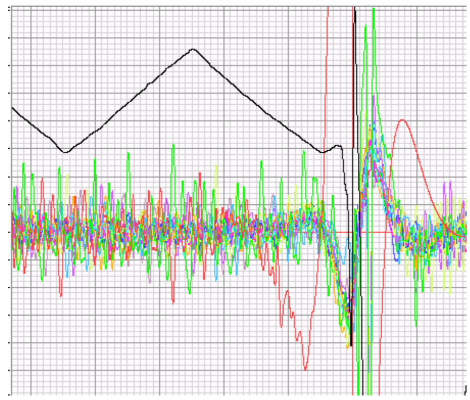
Blade Lengthening Event



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Future Directions

- Working with NASA Glenn to test system in high pressure burner rig, Q1 2006
  - 2500°F 1st stage turbine temperatures
- Compact PCI-based Tip Clearance Product
  - Power systems
  - Aero tests
  - Laboratory instrumentation
- More large frame power systems testing in turbine and compressor
- More spin pit testing