MICROWAVE BLADE TIP SENSOR: AN UPDATE

Jon Geisheimer
Vibro-Meter, Inc.
Atlanta Georgia

Vibro-Meter

Microwave Blade Tip Sensor: An Update

2006 NASA Seal/Secondary Air System Workshop
November 14, 2006

Jon Geisheimer, Senior Engineer
Vibro-Meter, Inc.
75 Fifth St. NW, Suite 316
Atlanta, GA 30340
404-526-6037
jon.geisheimer@vibro-meter.com

MEGGiTT

Vibro-Meter

Contents

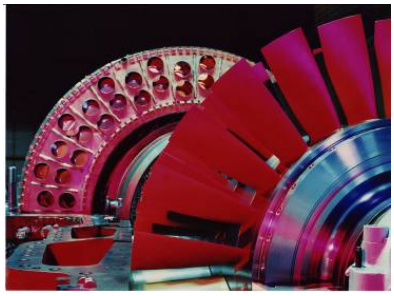
- System Overview
- Probe Testing
- Measurement Accuracy and Testing
- Current System Status/Future Work

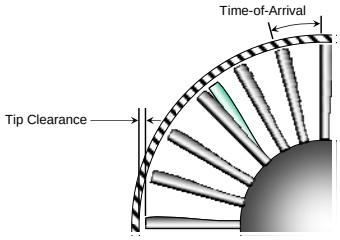
MEGGiTT

Vibro-Meter

Microwave Displacement Sensor Overview

- Non-contact measurements
  - Tip clearance
  - Blade time of arrival
- Key Technology Features
  - First stage turbine environment (1300°C+ gas path using bleed air cooling)
  - "See through" combustion products, flaming natural gas, steam, etc.
  - Individual measurements from every blade
  - One size fits all (not limited by 1.5 times diameter)



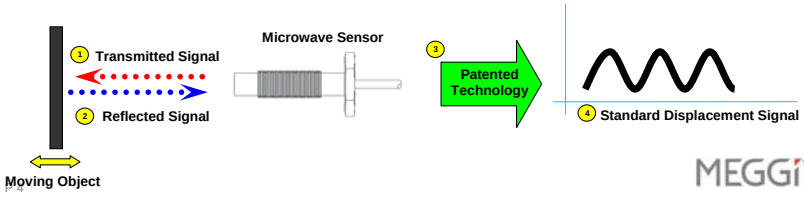


MEGGiTT

Vibro-Meter

Technology Overview

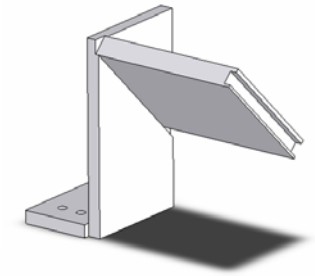
- Electrical Performance
  - Phase-based microwave technique
  - Measures distance smaller than the transmitted wavelength (~5 cm)
  - High signal to noise ratios (active system)
  - Large bandwidths- able to measure waveforms at all speeds (turning gear to full RPM)
- Measurement
  - Resolution less than 0.025 mm
  - Large displacement ranges (up to 13 mm)
  - Self-calibration to eliminate effects of thermal growth

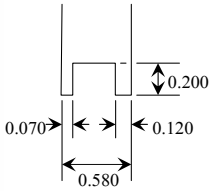


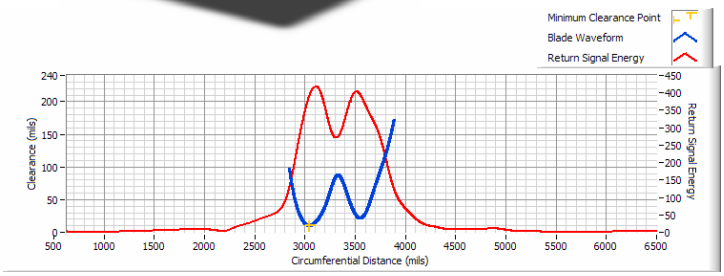
MEGGiTT

Vibro-Meter

Example Measurements







MEGGiTT

Vibro-Meter

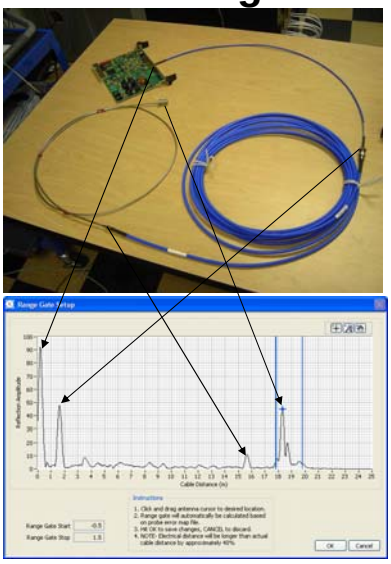
T2000 Rack Based System

- Land-based engines and tests
  - Aerospace ground tests
  - Power generating turbines
- Up to 12 channels (one channel per card)
- Minimum & average clearance to software or analog out
- 300MB/minute waveform data streamed to disk
- Future signal processing upgrades
  - Blade vibration
  - Blade health monitoring

MEGGiTT

Vibro-Meter

Sensor Diagnostics



- Sense changes in the cable
- Breaks in signal chain are localized very precisely—manifest as a parasitic signal return at a particular phase.
- Can be used to troubleshoot connections in the probe.
- Understand if changes are in the probe vs. in the reading.

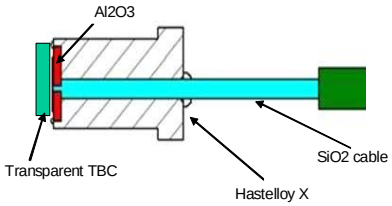
P 7

MEGGiTT

Sensor diagnostics is included with every product. Each connection from cable to cable is shown as a reflection visible in the TDR plot.

Vibro-Meter

Probe



- Made from same/similar materials as first stage turbine
  - Alumina ceramics
  - Nickel-based alloys
- High temperature SiO2 cable (900°C)
- Thermal/environmental protection of front face
- Low potential between center conductor and ground
  - No dielectric breakdown problems
- Fits into 0.5 inch hole

MEGGiTT

Vibro-Meter

Probe Testing

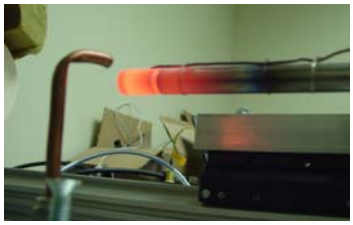
- Testing Focus
  - Cracking/separation due to coefficient of thermal expansion (CTE) mismatches and thermally induced stress
  - Oxidation of metal parts
- Internal laboratory testing
  - Isothermal bake to test oxidation
    - Initial 100 hour test at 800°C
    - 1000 hour interval
    - Go as long as we can
  - Thermal cycling to test CTE mismatches
    - Initial 20 cycles to 700°C
    - 300 cycles
    - Go as long as we can

MEGGiTT

Vibro-Meter

Thermal Cycling Rig

- Thermal cycling rig built to dip probe into a 900°C tube furnace
- Heat probe up slowly and then pull out to simulate a trip
- Thermocouple attached to probe for temperature monitoring
- Entire system automated to simulate a given temperature profile

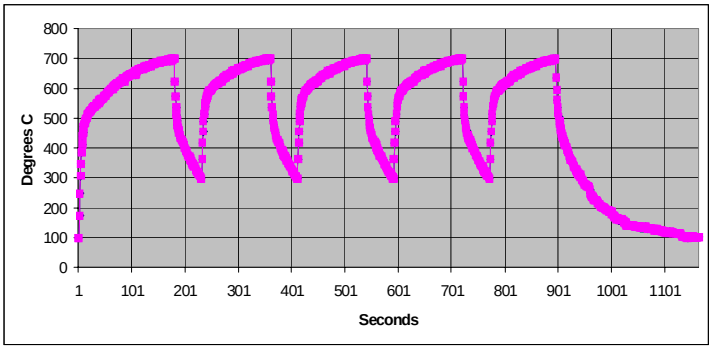


MEGGiTT

Vibro-Meter

Thermal Cycling Profile

- Most rapid thermal changes seen during a trip
- Cycling profile defined similar to a engine trip condition
  - Trip with a hot restart
  - Start from a “cold” condition

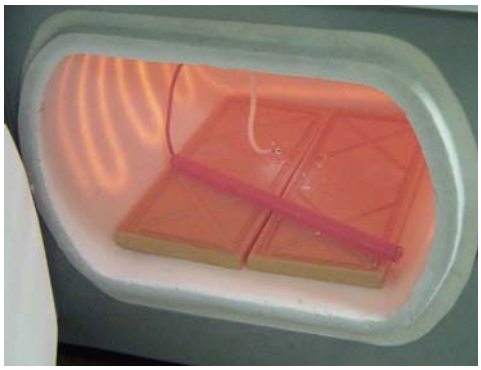


MEGGiTT

Vibro-Meter

Isothermal Oven

- Oven capable of 900°C
- Hook cable up to network analyzer through instrumentation port
- Continuous logging of probe performance

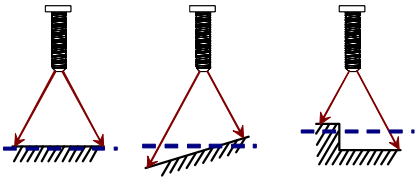


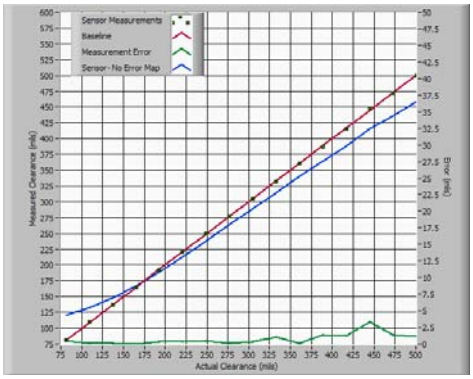
MEGGiTT

Vibro-Meter

Spatial Filtering

- "Large spot size" sensors see multiple geometry features
- Measurement is a composite of everything within the spot size
- Lasers better able to approximate the true geometry, but only look at a single area- this may not be where the closest clearance is locate
- Microwave sensor measures "distance" directly but have to map the "average" clearance to the minimum clearance
- Use an error map to calibrate measured clearance to actual clearance



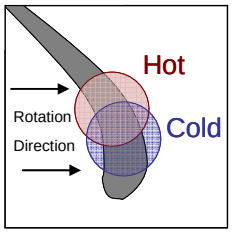


MEGGiTT

Vibro-Meter

Measurement Accuracy- Axial Shifts

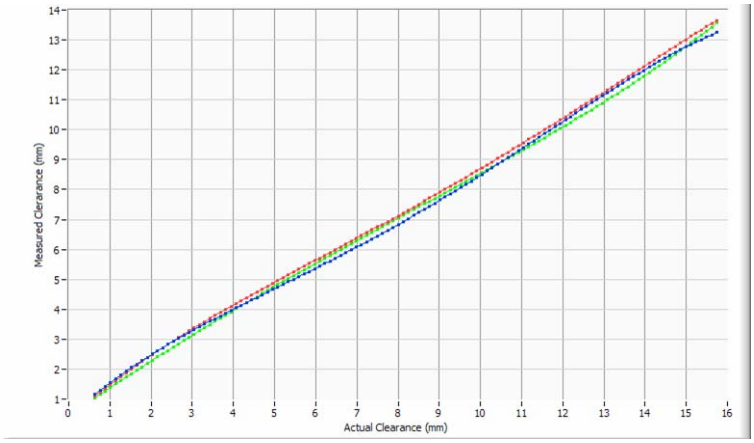
- Most sensors quote accuracy and linearity based upon a single calibrated target
- Real turbines have an additional complexity- axial shift due to thermal expansion and contraction of the rotor
- Geometry underneath the sensor changes
- With axial shifts, a perfectly linear sensor can give poor results
- Axial positions vary by stage and engine operating conditions
- This is probably more a problem in large frame power generating turbines than in aero applications



MEGGiTT

Vibro-Meter

Example Changes Due to Axial Shift



MEGGiTT

Vibro-Meter

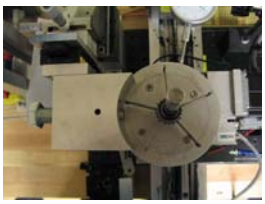
Accuracy Under Axial Shift Conditions

- Linearity could change several tenths of a millimeter across worse case axial shift conditions (large frame gas turbines)
- Signal processing techniques able to minimize this to +/- 0.1 mm or less
- Aero engine results expected to be more accurate (everything scales down)
- Continuing to investigate signal processing techniques to improve the measurement

MEGGiTT

Vibro-Meter

Measurement Repeatability Test

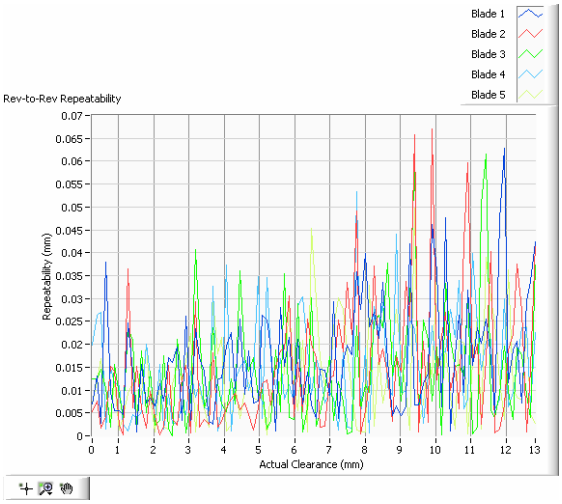


- Use rotary stage to rotate a synthetic blades in front of the sensor
- Five blades, each slightly different in height
- Rotary stage mounted on linear stage and moved to different clearances
- Look at the repeatability as function of distance

MEGGiTT

Vibro-Meter

Measurement Repeatability Results



MEGGiTT

Vibro-Meter

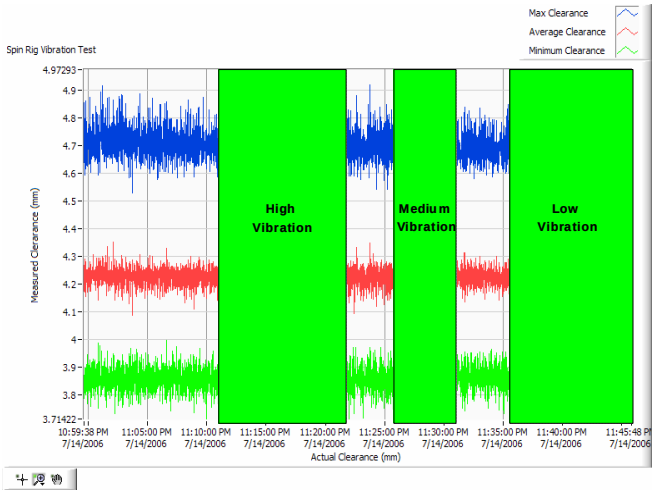
Vibration Testing

- Cable vibration can often induce extraneous signals into the measurement
- Industrial and aero turbines are vibration rich environments
- Simulate vibration and determine the effects
- Cable attached to a dental shaker
  - 60 Hz vibration frequency
  - Low, medium, high settings

MEGGiTT

Vibro-Meter

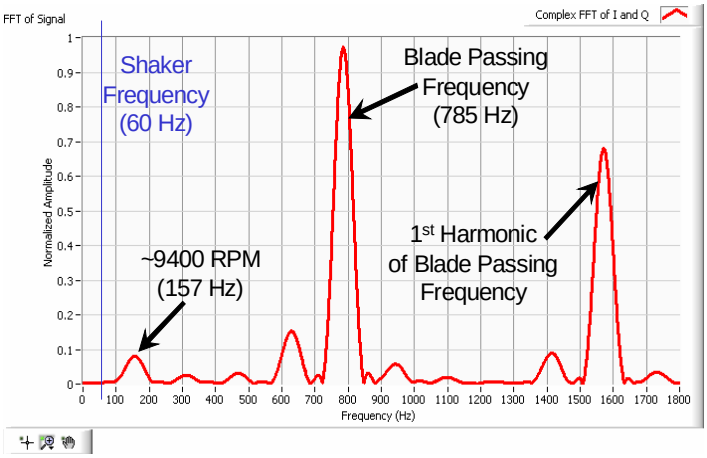
Vibration Testing- Time Domain Signal



MEGGiTT

Vibro-Meter

Vibration Testing- Frequency Domain



- No perceptible 60 Hz noise

MEGGiTT

Vibro-Meter

Current Status/Future Work

- Working on certifications for industrial market
- Completing next generation of probes with 12,000 hour design life Q1 2007
- Delivering prototype systems to several customers Q2 2007
- Delivered 2 channel prototype system to NASA Glenn
  - High Pressure Burner Rig testing in 2007
- Several large frame and aero gas turbines tests in 2007

MEGGiTT


MEGGiTT
smart engineering for
extreme environments
P 23