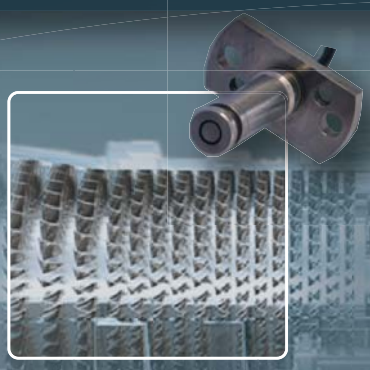
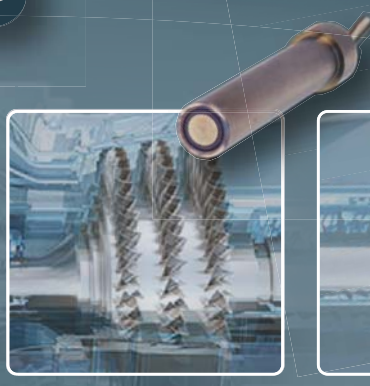
FOGALE Sensors

# Turbomachinery
## Blade Health Monitoring

**Capacitive sensors**
**for low & high temperature applications**



*LOW TEMPERATURE*

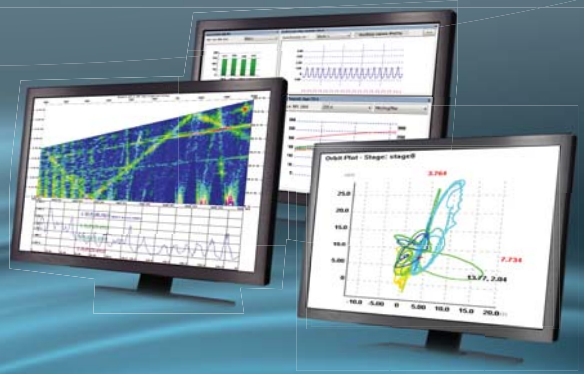


*HIGH TEMPERATURE*

*RADIAL & AXIAL DISPLACEMENT*

**System**
**for testing & monitoring**

**Software**
**for real-time measurements**



Solutions for Blade Tip Clearance and Blade Vibrations Issues

# Extending your Gas Turbine Operability with CAPABLADE Solutions

FOGALE Sensors

## Gas Turbine Blade Health Monitoring

*Blade Health Monitoring is a growing activity of the Condition Based Monitoring business focusing on key components of turbomachinery: The Blades! BHM brings major advantages profiting to plant operational assets.*

### Prevention of blade failures either by clearance issues or vibration issues

- Turbine blade tip rubbing prevention
  *(in running condition or prior warm restart in turning gear condition)*
- Blade vibrations monitoring
- Cracks and High Cycle Fatigue (HCF) assessment
- FODs and DODs detection
- LP Compressor fouling evolution monitoring
- LP Compressor stall detection

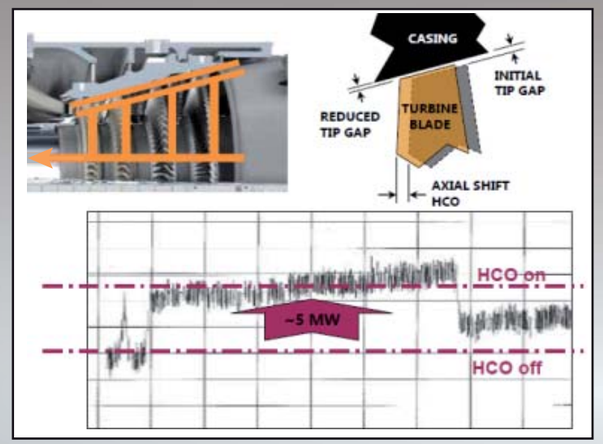
*HP turbine blade after rubbing*

### Extended benefits of BHM

- Early warnings of potential blading issues
- Prevention of costly breakdowns
- Downtime reduction
- Predictive maintenance/Outage optimization
- Components Lifetime Extension assessment
- Reduction of Life Cycle Costs (LCC)
- Improved utilization/operability

### Part-load or Flex-Op Performance Optimization by fine Active Clearance Control

- Increased efficiency
- Increased power output
- Reduction of consumption
- Reduction of CO2 emissions




*(source: 'Gas Turbine Technology: Challenges, Achievements, Outlook'; Menapace, IGTC2008)*

Blade Health Monitoring (BHM) is performed by mean of Real-time Blade Tip Clearance (BTC) and Blade Tip Timing (BTT) instrumentation based on non-invasive Capacitive technology.

Possible applications are Aero-engine ground testing, Gas turbine validation test rigs, Turbochargers static and dynamic test stands, Operational industrial gas turbines (trouble shooting and condition based monitoring), and even Aero-engines flying test beds.

**FOGALE Sensors proposes complete measurement solutions as well as components such as capacitive sensors, capacitive conditioning electronics, systems and software to perform effective BHM. The proposed solutions are developed and adapted to meet customer's requirements.**

## System

*FOGALE Sensors markets turnkey systems enabling BTC+BTT measurements for turbomachinery testing and monitoring. Systems are composed of conditioning electronics, acquisition system with real-time processing and analysis software.*

### MC925 module

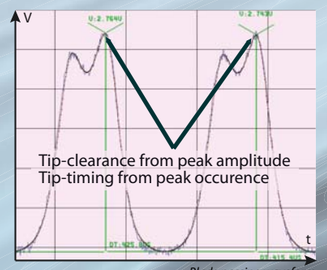
The MC925 capacitive conditioner is a high performance plug'n'play AC signal conditioner (bandwidth from <5Hz to 230kHz) for capacitive sensors used for BTC+BTT measurements performed even at very high temperature. Based on 30 years of expertise in the field of capacitance high accuracy metrology, the MC925 uses a unique digital compensation of the effects and variations of the line (up to 30m long) and sensor (up to 1400°C) electrical parameters (also monitored for sensor predictive maintenance) to measure the very effective capacitance between the sensor and the blade tip surface and characterize the blade passing waveform relative to Blade Tip Clearance and Blade Time-of-Arrival, with a very low noise level.

*MC925 capacitive module*

### CAPABLADE Fusion rack

CAPABLADE Fusion rack is a turnkey system for combined BTC and BTT measurements. The rack embeds up to 12 signal conditioning modules MC925 and/or MC935 for capacitive sensors, data acquisition, processing of the BTC+BTT measurements and local storage of the measurement. Distant client station can remotely access the Fusion server by an Ethernet connection to configure and monitor the measurements.

*CAPABLADE Fusion rack with MC925 & MC935 capacitive modules*




*Blade passing waveform*

### Combined BTC and BTT identification

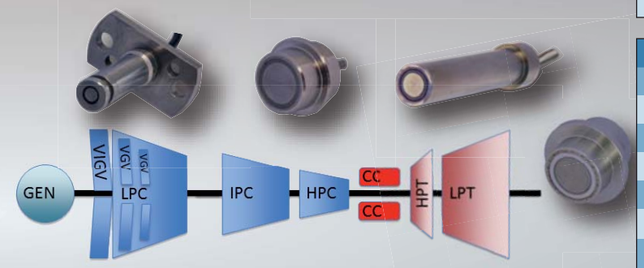
Blade passing signal is sampled at high frequency and waveform is resolved by a least-square minimization to extract for each blade, at each rotation, on each sensors, the peak amplitude characteristic of the blade-to-sensor distance, and the blade tip timing extrapolated into blade vibrations.

## Sensors

*FOGALE Sensors proposes capacitive sensors with standard and customized designs for both static (distance) and dynamic (BTC+BTT) measurements, applicable from low temperature (<0°C) to gas turbine harsh environment (up to 1300°C without cooling). Sensors, especially for harsh environment applications, are intensively tested and validated for long lasting operation.*

| Low Temperature BTC + BTT measurement sensors |
|---|
| Up to 200°C |
| Up to 200 bar |
| Maximum measurement range from 0.05mm to 20mm |
| Coaxial or triaxial design |
| Various casing fitting applicable (flange, screw-in, clamps, etc.) |
| Captive design to prevent DOD |
| Teflon cable extension (<200°C) up to 30m long |
| Calibrated vs. blade tip geometry |

| High Temperature BTC+BTT measurement sensors |
|---|
| Up to 1400°C without cooling |
| Up to 200 bar |
| Maximum measurement range from 0.5mm to 12mm |
| Coaxial design |
| Various casing fitting applicable (flange, screw-in, clamps, etc.) |
| Captive design to prevent DOD |
| Mineral cable extension (<1000°C and >200°C) up to 6m and Teflon cable extension (<200°C) up to 28m |
| Calibrated vs. blade tip geometry |




*Powergen GT train layout: example of sensors applicable*

| Radial and axial displacements measurement sensors |
|---|
| Up to 500°C |
| Up to 180 bar |
| Maximum measurement range from 0.05mm to 20mm |
| Triaxial design |
| Various casing fitting applicable (flange, screw-in, clamps, etc.) |
| Captive design to prevent DOD |
| Mineral cable extension (<500°C and >200°C) up to 2m + Teflon cable extension (<200°C) up to 10m |
| Calibrated vs. representative target surface |

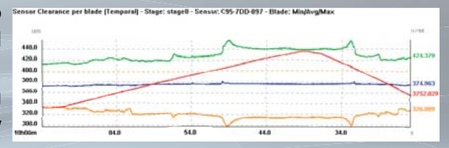
## Software/Real-time analysis

*FOGALE Sensors releases software suites dedicated to the BTC+BTT measurements. The CAPABLADE software suite enables a number of specific real-time monitoring and analysis functions of the measurements.*

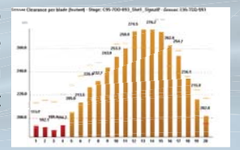
### Clearance monitoring

Clearance monitoring generates at every rotation data of all measured blade tip clearances variation due to thermal and centrifugal effect, with specific warning and alarms to prevent blade tip rubbing. Exclusive long-term processing allows to trend clearance variation during the lifetime of the GT to optimize operational performances.

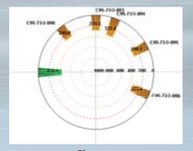
Clearance monitoring is also possible at low speed when rotating on turning gear to ensure safe clearance margin prior GT warm restart (warm restart rubbing prevention).



*Min/Max/Avg Clearance history*



*Clearance per blade*



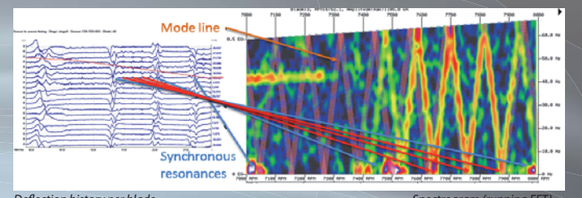
*Clearance per sensor*

### Blade vibrations monitoring

Blade vibrations monitoring enables the characterization of synchronous and non-synchronous vibrational response of all measured blades.

Modal analysis allows trending of the frequencies and amplitudes of the Eigen modes to detect blade failures.

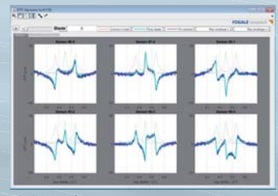
Vibrations history facilitates blade mechanical integrity assessment (fatigue) for predictive maintenance and parts remaining lifetime estimation.




*Deflection history per blade* *Spectrogram (running FFT)*

### Other features and analysis

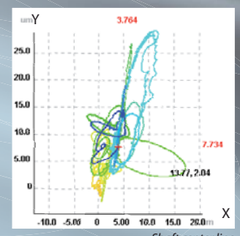
- Continuous local data storage
- Data streaming in OPC
- Alarm triggered data acquisition
- Synchronous resonance analysis
- Measurement post-processing and trending
- Static axial and radial clearance measurements



*Blade HA software: multiple synchronous resonances analysis*

### Shaft Center Line

Combined BTC + BTT measurements can be extrapolated into shaft center line to monitor the center of rotation of the measured stages.




*Shaft center line*

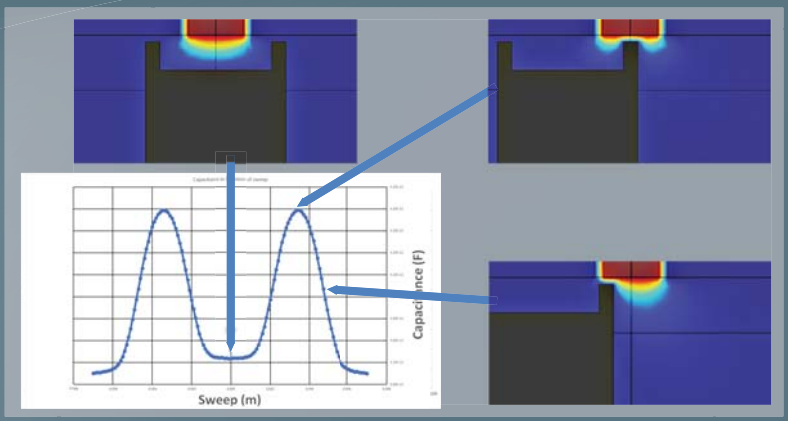
**FOGALE** Sensors

## Expert support & service

*FOGALE Sensors offers a number of services to support customers in successful application of the BTC+BTT measurement technology.*

### Sensor dimensioning optimization and custom design

FOGALE Sensors capacitive experts provide an efficient support in optimizing the sensor design to meet the customers measurement specifications (range, accuracy, conditions, blade geometry) taking in account the whole measurement chain (sensor, cable, MC925, blade passing waveform fitting models, casing implementation). Measurements on complex blade tip geometry can be optimized by mean of FEM calculation of the capacitance between the sensor and the target.




*FEM capacitance calculation of blade passing in front of a sensor*

### On-site support and service

FOGALE Sensors can perform on-site support with field engineers qualified to industrial safety regulation (CCNSG Safety Passport). The proposed support consists either in training and commissioning on delivered equipment, test campaign support, short period rental of measurement equipment, data analysis, and general advises on application of BTC+BTT measurement for Blade Health Monitoring.

### System maintenance and upgrade

FOGALE Sensors provides after sales service to maintain availability of the measurement systems upon base of yearly maintenance contract, or on specific request (subject to tendering). Maintenance service can either be performed at FOGALE Sensors premises by return of the equipment or at customer's site by field service engineers.

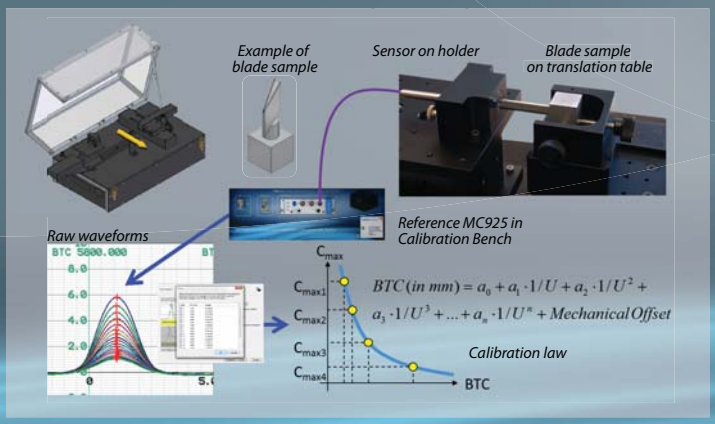
### Sensor Calibration

FOGALE Sensors performs sensor calibration with a dedicated Automated Calibration Bench simulating the passage of the blade in front of the sensor at different steps over the sensor measurement range, using target samples representative of the blade tip geometry to be measured.

*FOGALE Sensors Automated Calibration Bench*

The calibration method is cost-effective as:

- Bench is stand alone and does not require the use of the full Fusion system
- Bench is easy to handle with modular fitting of sensors and blade samples, and manual accurate zeroing
- Blade samples can be manufactured in rapid prototyping
- Software outputs calibration parameters and certificate report immediately after the calibration procedure
- Calibration parameters can be exported to CAPABLADE Software with no additional processing




*Calibration method*

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