PENTAIR

CAPACISENSE

HIGH TEMPERATURE CLEARANCE AND VIBRATION MONITORING SYSTEMS

INDUSTRIAL HEAT TRACING SOLUTIONS | WWW.CAPACISENSE.COM

PENTAIR

ADVANCED INDUSTRIAL SOLUTIONS

As the world's largest provider of complete electrical heat management systems, primarily for the general process, oil and gas, chemical, and power generation industries, Pentair provides innovative products and turnkey solutions under market-leading brands—Raychem and Tracer. Our premiere turnkey solutions include full life cycle support—ranging from front-end engineering and installation to maintenance and operation services. Our global experience and office presence in 50 countries uniquely position us to manage the heat needed for projects of any size and scope.

THE HEART OF OUR SOLUTIONS

As the inventor of self-regulating heat tracing, our Raychem brand is recognized for technical leadership in the industries we serve. Raychem cable delivers the appropriate amount of heat exactly when and where it is needed, adjusting the output produced in response to ambient and process conditions, making it ideal for heat management systems. Since inventing the technology, Pentair has sold over 1.6 billion feet (500,000 km) of Raychem self-regulating cable.

In addition to the self-regulating heat-tracing technology, we also provide parallel constant wattage cables, series polymer insulated cables and series mineral insulated cables for a full range of temperature needs.

The Raychem brand of mineral insulated heating cables and wiring have led the industry for more than 75 years. Able to withstand extreme, harsh environments, Raychem heat-tracing cables provide the most reliable solution for high-temperature applications. Recently rebranded to Raychem, these cables perfectly reflect the superior reliability that comes with this product brand.

Raychem control & monitoring products represent the industry's most complete range of dedicated heat-tracing control and monitoring systems, from simple thermostats to advanced networked systems, with easy-to-use interface technologies that put information and programming at your fingertips.

Our Tracer Turnkey Solutions Team is widely regarded as the premiere provider of industrial turnkey heat-tracing solutions. With our full suite of services, from front-end engineering and installation to maintenance and operation services, we are capable of handling heat-tracing projects of any size and scope. By focusing on safety and utilizing time-tested methods and solutions, our heat-tracing designs and installations are timely, thorough, and cost-effective.

POLE TO POLE, ONE RELIABLE PARTNER IN HEAT TRACING

CAPACISENSE

MONITOR BLADES IN AN OPERATIONAL TURBINE, EVEN AT HIGH TEMPERATURES

CapaciSense systems combine blade tip clearance and vibration monitoring using high bandwidth electronics to provide two sets of data from one state-of-the-art turbine sensor. With sensors (probes) that are able to withstand temperatures of 1400°C/2550°F, CapaciSense systems enable you to monitor turbines at temperature and in continuous operation.

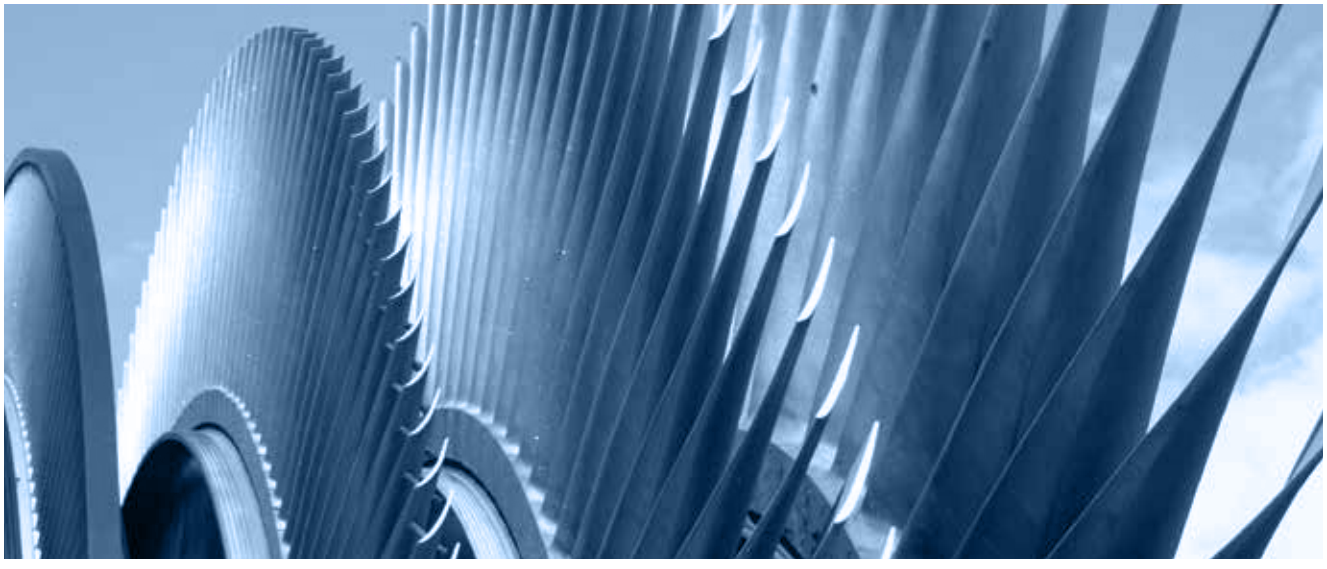
By providing a virtual window to see inside your operating turbine engine, CapaciSense condition monitoring systems:

- Provide accurate real-time data to help achieve smaller clearances, optimise the machine's efficiency; therfore, cutting down fuel costs
- Monitor differential thermal growth during warm restarts to prevent tip damage caused by blade rubbing
- Monitor vibrations through tip timing to provide an early warning of problems or potential failure, preventing unplanned and expensive outages or even catastrophic failure

CapaciSense systems are used in gas turbines within the power generation and aerospace industries, although they are also suitable for other applications where a conventional proximity probe would not survive the environment.

CapaciSense systems are based on capacitance theory and contain sensors, turbine mounted/local electronics, remote electronics and a control and processing module with software.

This document gives a brief overview of what CapaciSense has to offer. Contact your local representative to discuss your needs.



BACKGROUND INFORMATION

CapaciSense systems were developed in the 1980's with the support of what is now the Pyrotenax business of Pentair, the market leader in high temperature mineral insulated cable. Now part of Pentair Industrial Heat Tracing Solutions, the CapaciSense product has matured into a full system and service package. Currently employed worldwide within the power generation and aerospace industries, CapaciSense sensors are favoured for their ability to survive extreme temperatures for several years, enabling the whole engine to be monitored continuously, not only the lower temperature compressor areas.

CapaciSense is at the forefront of solutions for blade condition monitoring in extreme environments.

KEY DEVELOPMENTS AND MILESTONES

1988 First triax cable for capacitive sensors supplied

1996 First development sensor design

1997 Sensor patent granted

2003 First sensors into production engines

2006 CapaciSense brand launched, 150th sensor designed

2006 Industrialised ATEX and FM approved systems

2007 First retrofit installation and 5 Series demodulator launched

2008 5 Series oscillator launched

2009 5 Series ATEX approval and blade clearance and vibration software launch

2010 5 Series FM approval

2012 Merge with Pentair, Probe 200 designed

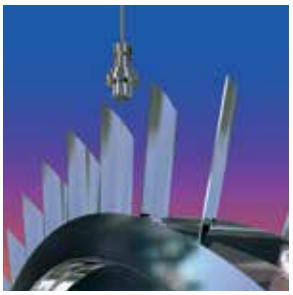
2015 CapaciSence SOLO Launched

APPLICATIONS

ENGINE DESIGN VERIFICATION

A driving factor when designing gas turbines, whether it be power generation or aerospace, is their fuel efficiency. Higher fuel efficiency means lower operating costs, often driving the decision on which turbine to adopt. Most of the world's leading developers of power generation turbines have used our systems for design verification of blade tip to shroud clearances at high temperatures, supplanting the older technologies.

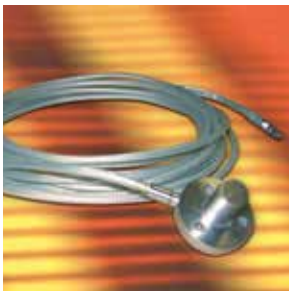
By using our CapaciSense system, turbine designers can get a live picture of the blade tip clearances in prototype engines during all phases of the engine's operation.



OPERATING ENGINE

Designers of some of the world's largest power generating turbines are now choosing to install our condition monitoring system to continuously monitor blade clearances and vibration. Our system offers data for informed user control of adaptive clearance systems.

If you are responsible for insuring an operator engine, by installing a CapaciSence system you can have extra confidence that the asset is being correctly operated and potentail damage caused by warm re-starts can be prevented.



RETROFIT

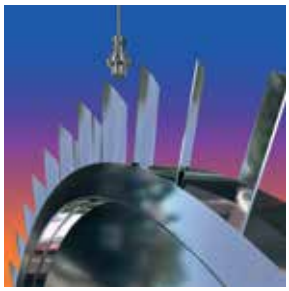
As downtime for maintenance is expensive, it is imperative that this is minimised and performed at the right time with informed knowledge of current engine conditions. By retrofitting with a CapaciSense system, the operator can be given forward notice of potential blade failure due to blade rubbing or vibration. This additional intelligence on the engine operation allows warm restarts to be safely performed with the knowledge that differential thermal expansion isn't going to cause a blade rub which will result in costly repairs.

With approvals for Europe and North America, our systems can be used safely in hazardous areas. This is of particular interest for those considering retrofitting turbines with additional condition monitoring sensors for predictive maintenance or to check blades in "near rubbing" conditions.

NON-GAS TURBINES

While CapaciSense system's primary application is in gas turbines, it can be used for proximity applications where conventional systems are inadequate, for example gas seal clearances, impellers such as turbo chargers, or piston clearance measurement.

WHY CHOOSE A CAPACISENSE SYSTEM?



IMPROVED RELIABILITY AND REDUCED MAINTENANCE COSTS

By providing real time data, you will access early warning signals of potential problems, which will help you to make decisions and avoid unplanned and expensive outages or even catastrophic failure.

Turbines are extremely sensitive to blade tip rubbing, which can be a cause of failure. Our tip clearance functionality will monitor differential thermal growth during warm restarts and the information provided helps you to prevent tip damage caused by blade rubbing.

Our tip timing functionality will monitor the arrival time of a blade tip and use this to calculate blade deflections and identify vibration.

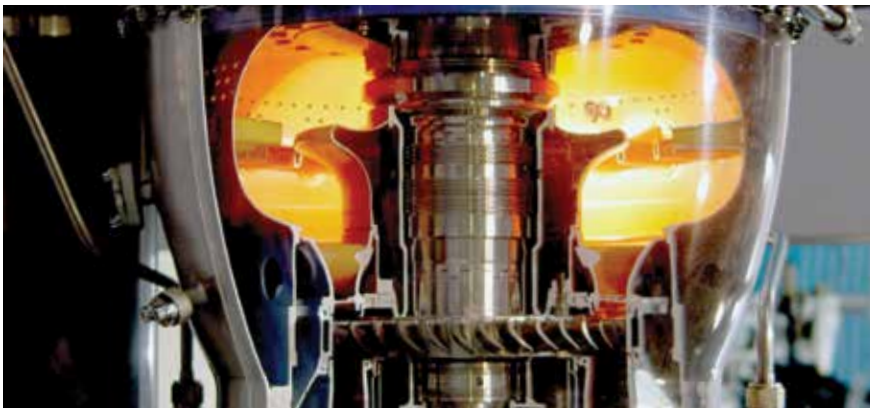
IMPROVED OUTPUT AND EFFICIENCY

Due to the high temperatures our sensors can sustain 1400°C/2552°F, even the turbine stage blade clearance can be measured, an important factor as this means the whole engine can be monitored, not just the lower temperature compressor areas. This raises the possibility of controlling the various stages independently and optimising the whole turbine rather than just one zone.

As the turbine's fuel efficiency is directly affected by the size of the clearance, designers and manufacturers are using the live outputs to adjust clearances to a minimum on working turbines and therefore gaining greater fuel efficiencies.

SUITABLE FOR HAZARDOUS LOCATIONS

Both the 5 Series FM system and CapaciSense SOLO are approved for use in hazardous locations in both Europe and North America (SOLO North American pending at time of print). The FM system gives you the option of installing the oscillators within the hazardous area and connecting to 6 m (19.7 ft) of probe cabling where as the CapaciSense SOLO has to be in a safe area but can drive up to 20 m (65.6ft) of cable into a hazardous area.



TIP TIMING AND CLEARANCE FROM ONE SENSOR

CapaciSense systems can provide both tip clearance and tip timing from one state-of-the-art sensor. With the advent of high speed electronics and software, the blade passing signal, which has traditionally provided only clearance information, is now capable of resolving blade time of arrival. Traditional methods for measuring blade fatigue include strain gauging and optical tip timing. Whilst strain gauges provide accurate information, they only provide that information for the blades which are instrumented and these gauges are not suitable for a production environment.

Optical sensors provide excellent tip timing data but only for short periods of time before their optics became fogged with contamination. By using already proven CapaciSense clearance sensors, additional data can be derived on blade vibration without the need to install additional instrumentation.

LONG LASTING

For condition monitoring applications, sensors need to perform well over extended periods of time. CapaciSense sensors are proven to be robust. The four sensors pictured at the top right have had years in the hottest turbine zone in one of the world's largest turbines. They were removed during regular servicing and are still functional. One sensor has been polished to remove combustion product deposits—it shows it is still close to its original condition. All CapaciSense sensors have patented fully captive components which limits the risk of the sensor breaking apart into the engine—even if it is damaged.

TRUSTED HISTORY

Our systems have been successfully used worldwide by gas turbine manufacturers to verify the frame clearances in extreme environments for many years.

CUSTOMISED SOLUTIONS

The CapaciSense team provides a full design and development service on every project in order to meet the requirements of your application. We custom make our sensors to suit your environment:

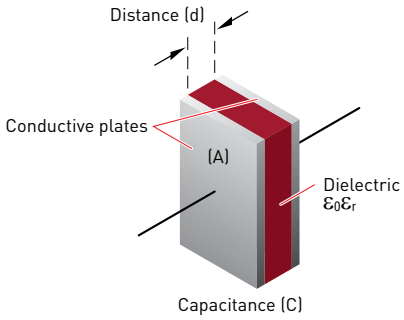
- Temperature extremes (>1400°C/2250°F)
- Temperature cycling
- Vibration
- Moisture (including on-line water wash)

Calibration disc design and manufacture to replicate actual blade tip profiles, sensor calibration and a full installation service are offered as part of our solution. It is our goal not to provide components but to provide whole solutions.

MAKING YOUR LIFE EASIER

In 2007/2008 when the 5 Series was launched not only did we improve the signal quality, we introduced calibration download from the oscillator to the demodulator and the ability to confirm the electronics were connected to the right channel. With CapaciSense SOLO we have gone one better, where the calibration data is now stored on the probe itself! You can now plug any CapaciSence probe into any SOLO device and measure clearance without the need to genuinely recalibrate or assess calibration data.

HOW CAPACISENSE WORKS



$$C=\frac{\varepsilon_0\varepsilon_r A}{d}$$

Where:

C= Capacitance

ε_r= Relative permittivity (constant in this application)

ε_0= Permittivity of free space (constant)

A= Overlapping electrode area (constant in this application)

d= Electrode separation

As C is proportional to 1/d, by measuring C, d can be determined.

CapaciSense is a non-contact measurement system that uses capacitance to detect the distance of an object and its time of arrival.

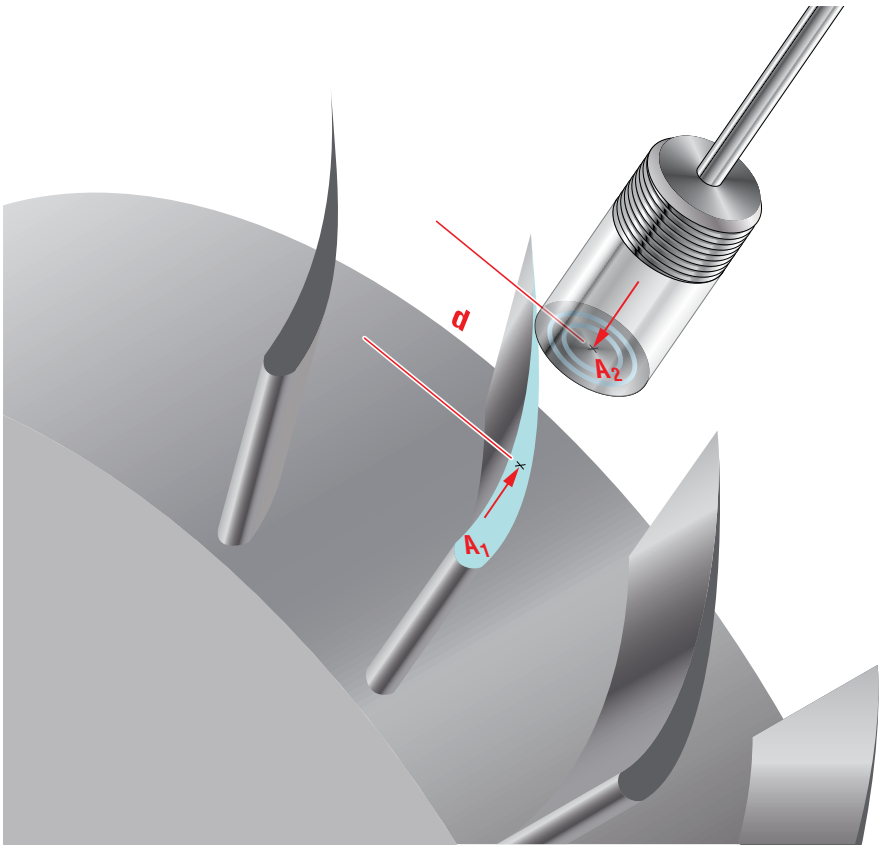
CAPACITIVE TECHNOLOGY

The core functionality of the system is relatively simple and uses capacitance parallel plate theory.

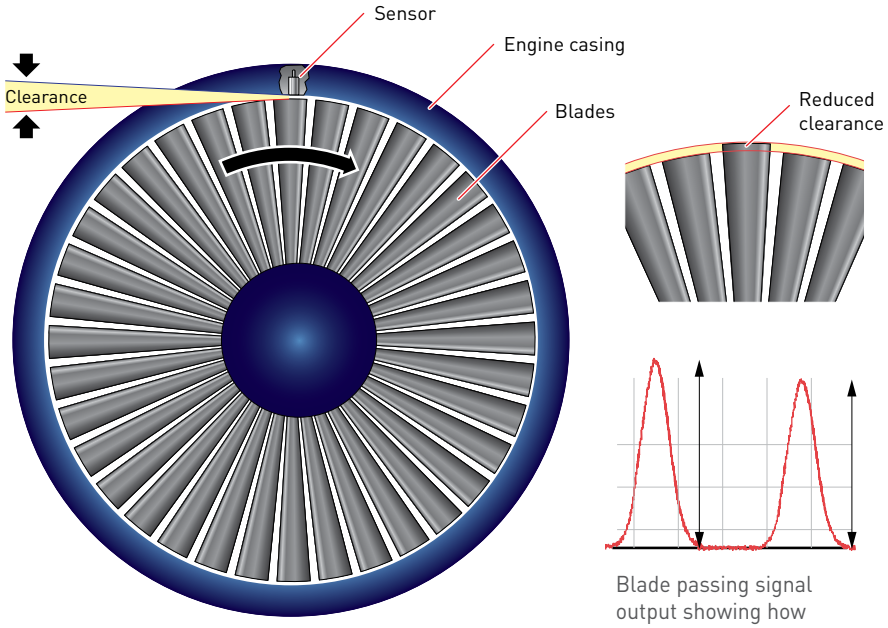
The overlapping electrode area, which is specific to blade profile (A1) and electrode dimensions (A2), is assumed to be constant. The permittivity can also be considered to be constant as the small changes which do occur due to combustion have proven to be negligible.

This theory gives us the ability to calculate the distance separating blade tip to sensor 'plates' by measuring the capacitance. The advanced electronics of the system convert this capacitance into a voltage, allowing a direct correlation between voltage and distance to be established while the blade is passing at over the speed of sound.

As the returned capacitance from a system such as this is extremely small (tens of femto farrads), advanced techniques need to be utilised to accurately measure them—see our electronic options described later.

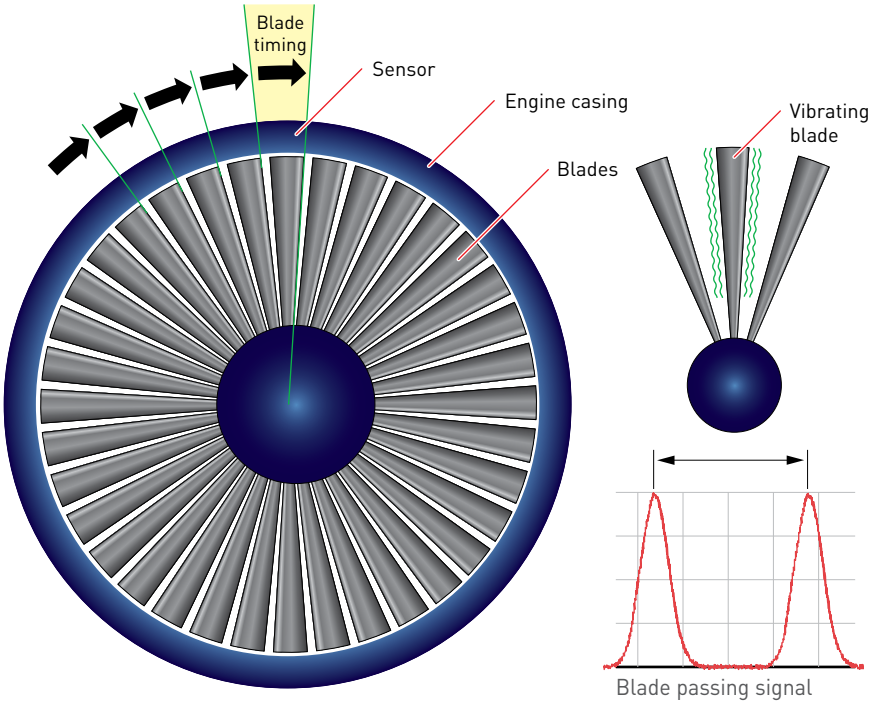


TIP CLEARANCE



Blade passing signal output showing how measuring pulse amplitude is used for clearance monitoring

TIP TIMING



Blade passing signal output showing how measuring time of arrival is used for vibration monitoring

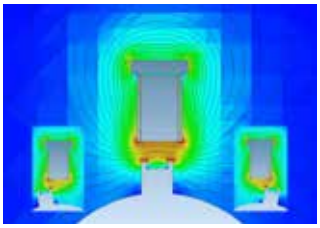
SENSOR AND CABLE ASSEMBLIES (PROBES)

APPROVALS AND CERTIFICATIONS

CapaciSense high temperature clearance and vibration monitoring systems are approved and certified for use in nonhazardous and hazardous locations by FM Approvals and Baseefa.

All CapaciSense probes are designed and manufactured in the Washington UK facilities. Significant investment has been made over recent years to update the laser welding of the probes and to allow parts to be machined on-site. The Mineral Insulated (MI) cable at the heart of higher temperature probes, continues to be manufactured and therefore also controlled in Washington.

Finite Element Analysis (FEA) tools are used to further understanding of the technology and make the next generation of probes even better than the last.



All of the CapaciSense Probes are triaxial in construction, featuring:

- A central "sensing" electrode
- A driven guard for reduction of leakage capacitance
- Outer screen/body for noise reduction
- All inner components are captive to prevent metallic parts completely falling into the blades
- Custom designs (approaching 300 to date)
- Optimised for continuous surfaces or bladed systems depending on the application
- Super-alloy construction to allow use over 1400°C (2552°F)

HIGH TEMPERATURE SENSORS

Used predominantly for turbine applications. The inclusion of flutes and cooling apertures has advanced the operational capabilities of these designs over to 1400°C/2552°F, allowing several years of operation.

MID-RANGE TEMPERATURE SENSORS

Typically for FM compressor applications or AM systems, the mid-temperature range of designs have an operating temperature of up to 1000°C/1832°F. The mid-range sensors have the same characteristics as the high temperature range without the cooling functionality. These sensors can be used at higher temperatures although their life will be shortened.

LOWER TEMPERATURE SENSORS

For operational use at temperatures below 200°C/392°F, the low temperature design incorporates flexible triaxial cable as opposed to mineral insulated cable. Whilst still using the specialist assembly techniques, the sensors benefit from a lower cost and easier installation.

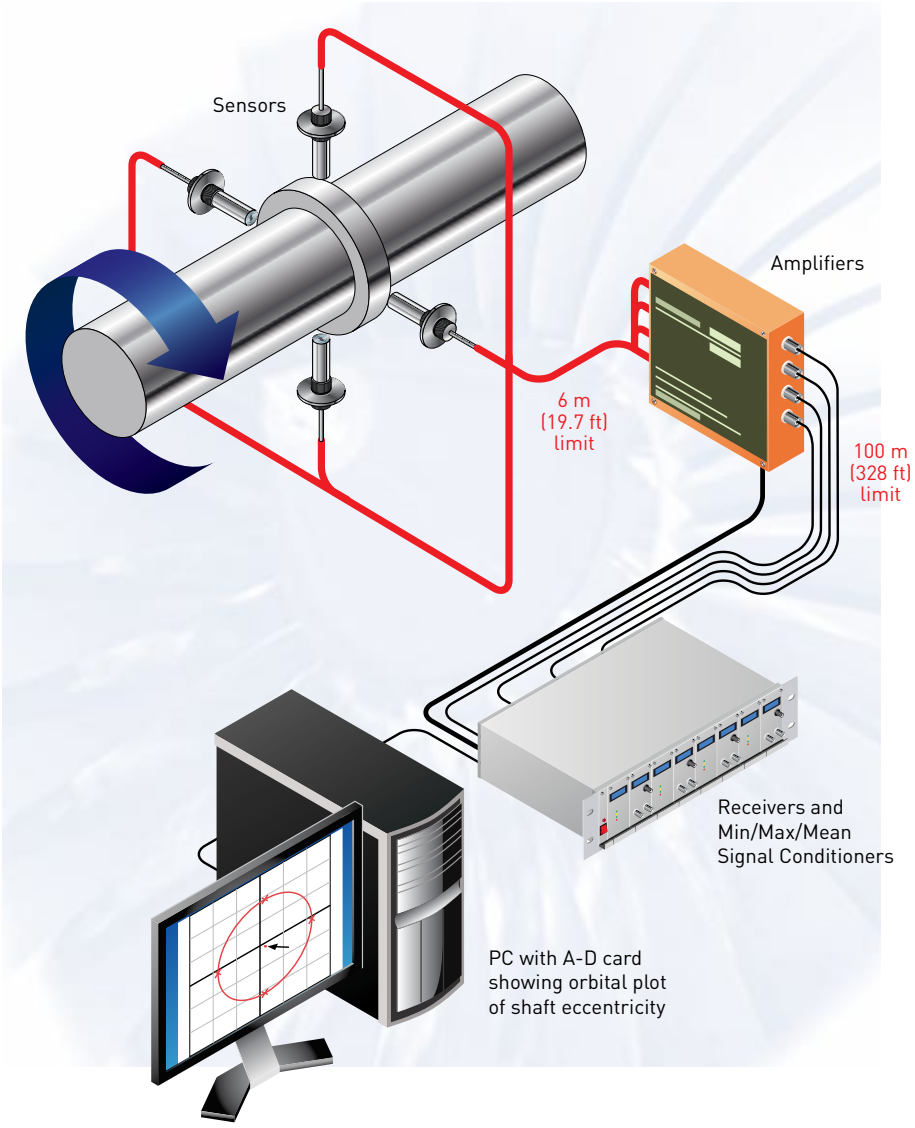
ELECTRONICS FOR CONTINUOUS SURFACES

AM SYSTEM

The system is ideally suited to measuring slow moving clearances in harsh conditions.

Probes, with cable up to 6 m long connect to a locally mounted AM Oscillator Enclosure. The enclosure can house from one to four amplifies allowing one to four probes to be connected. Output leads from the enclosure plug into a 19" Rack holding up to eight receivers and so can be used with two enclosures. A "DC" signal is available which is either proportional to clearance or capacitance. As this is such a low frequency application, most measurement systems can record and linearise it into engineering clearance units using suitable calibration data. Optional MIN/MAX/MEAN modules are however available to reduce the measurement demands.

SYSTEM COMPONENTS



BLADED SYSTEMS

5 SERIES FM SYSTEM

Built on the hugely successful 4 Series, the 5 Series offers a "two box" solution to your capacitive sensing needs. A small oscillator is installed at the end of a probe, up to 6 m long, this is then connected to a 19" rack by a length of coax cable up to 100 m long. The 19" rack can hold up to 12 demodulators and hence be connected to up to 12 oscillators and probes.

The 5 Series offers backward compatibility with the 4 Series solution and single channels can be purchased to allow channel count upgrades to existing installations.

While Pentair recommends the 5 Series be connected to our Control and Processing Module (CPM) for full control and flexibility, it is possible to manually configure the system and use your own data recording systems to measure an "average" RMS clearance signal or the raw blade passing signal (BPS) for processing into blade by blade clearance.

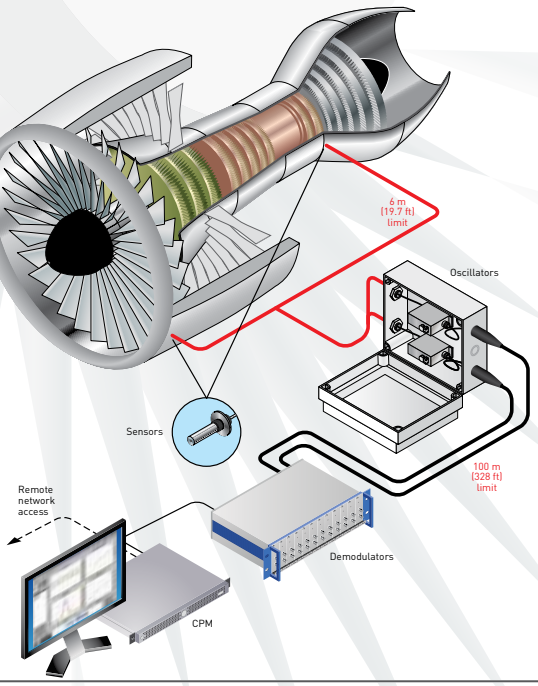
When used with the CPM, 12 voltage-free alarm contacts are available on each demodulator rack and these can be configured to warn the user of clearances falling outside of tolerance.

Probe calibration data can be stored within the oscillators to be automatically downloaded to the CPM for signal linearization and confirmation that you know which probe you are monitoring.

With an impressive 400 kHz maximum bandwidth, the 5 Series is possibly the fastest commercial capacitive monitoring system available.

The 5 Series has both ATEX and FM approval for use in Hazardous areas.

SYSTEM COMPONENTS



SOLO SYSTEM

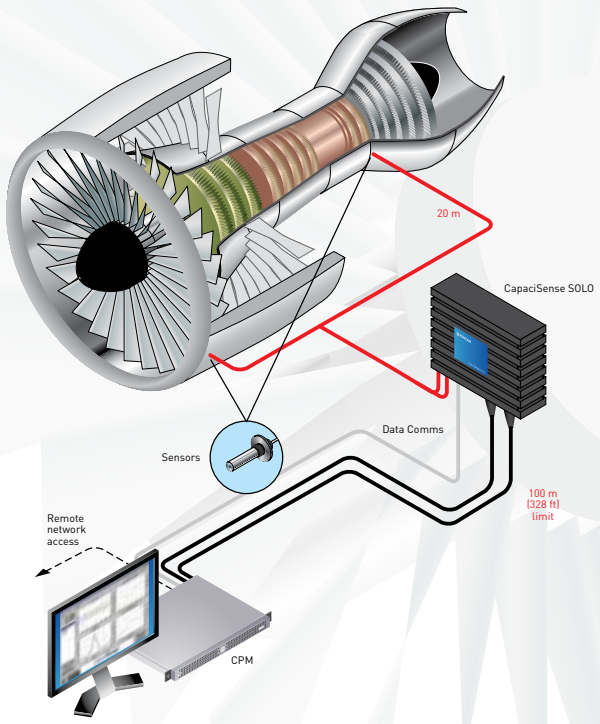
Designed to be a perfect solution for industrial installations, the SOLO is a "one box" electronic solution. Each SOLO unit can be connected to up to 4 probes with up to 20 m (note: longer cables may be possible in some situations) of cable connected to them. The system outputs a blade passing signal (BPS) for each channel which can be recorded by your own measurement system, but is truly designed to work in conjunction with the CapaciSense CPM to give live average and blade by blade clearance data, as well as time of arrival (TOA) tip timing data. The CPM can also perform full configuration of the SOLO via its RJ45 network connection.

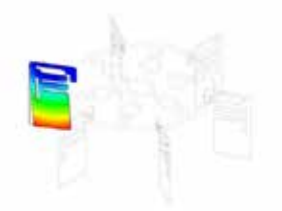
Unlike the 5 Series, custom matching of probes to the electronics is no longer required, meaning probes can be swapped from one system to another. To facilitate the ease of use, CapaciSense probes now offer "smart" labels which are read by SOLO. Upon installation all of the probe details, including calibration, are passed to the CPM. To ensure you don't have your cables crossed, SOLO even produces a test signal to confirm the channel numbers.

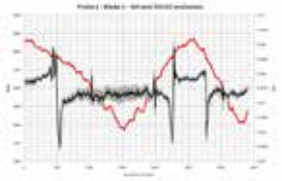
With a bandwidth of over 350 kHz, it doesn't quite equal the 5 Series but is more than fast enough for most applications.

As a one box solution SOLO is ideally suited for retrofitting to existing rotating equipment. CapaciSense Solo has North American ATEX approval. (Hazardous areas approval for North America in process at time of writing)

SYSTEM COMPONENTS



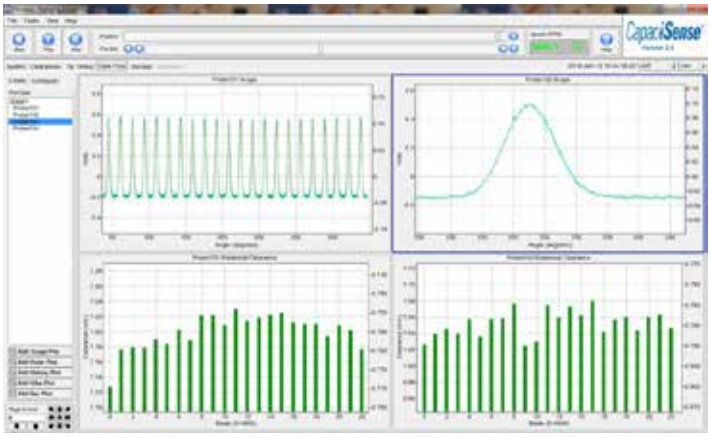




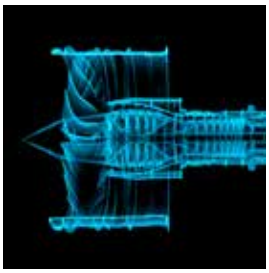
CONTROL AND PROCESSING MODULE WITH SOFTWARE

Used initially to configure the system and to present the data in values, figures and visual plots and charts:

- Can control both 5 Series and SOLO
- Up to 10 MHz simultaneous sampling in control and processing modules (CPM) from analogue BPS signal
- Built-in data acquisition and software means no analogue data for the user to acquire and analyse, although the raw data is presented for advanced users to analyse
- Gain and bandwidth settings controlled via CPM
- Auto download of sensor calibration means you can never mix your signals
- Auto setup—no jumper settings
- Sync signal—used to synchronise multiple racks for the pooling of data
- Hard disc for data storage and further analysis
- 5 Series and SOLO configuration to allow Ultra Slow Mode
- Once per rev input (engine speed/blade identification)
- Addition of blade vibration monitoring from the same system that gives you the tip clearance (simple software update)
- Remote access from Microsoft Windows® or Linux® based machines—no sofware needs to be installed.
- Modbus and DLL interface to other systems

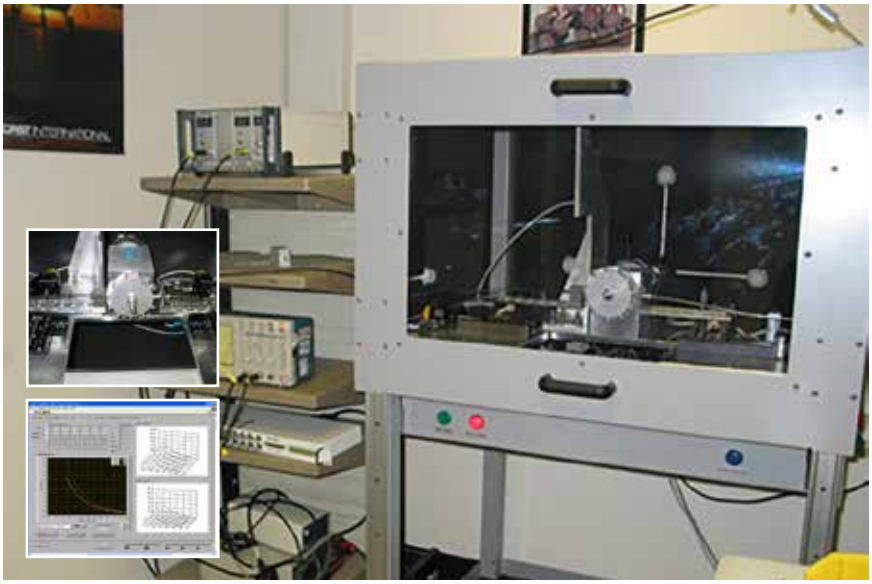


SERVICE & SUPPORT



Pentair offers a full design service to provide a turnkey solution to your measurement needs. As well as providing the custom designed probes and user tailored electronics, all systems can be calibrated to your specific targets – something which is especially important for bladed systems.

Once you have purchased our system, you can rely upon first class after sales support for training, site installation assistance or simply to ask a question. We are here to help.



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