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Latest Developments In The Use Of Non-Contact Capacitive Displacement and Gap Sensors In Extreme Environment Applications

SUMMARY

Capacitec presents specific examples of applications where capacitive technology has been adapted to measure very precise physical dimensions in extreme environments such as cryogenic to 1,000°C, radiation to 10^{11} Rads, magnetic fields to 5 Tesla, utilizing very small sensors with probe diameters down to 1.0 mm.

- Manufacture of automotive glass at 800°C
- Disk brake dimensional analysis at 400°C mounted on a dynamometer
- Nuclear fuel rod gap and other physical dimensions
- Satellite instrument analysis in cryogenic vacuum chambers to minus 273°C
- Extremely small displacement sensors (1.0 mm OD) and extremely thin gap sensors (100 microns thick) for difficult to access gap locations

Principle of Operation

Capacitive non-contact displacement sensor probes have a central sensing element with a typical diameter of between 2 to 5 mm. A ring layer called a guard, which is approximately twice the diameter of the sensor, surrounds the sensor. The guard ring, when driven, alleviates degrading fringing effects, which would rob the capacitive sensor of its range. Both the sensor and guard are isolated from each other. The center conductor wire of a 100% shielded coaxial cable electrically connects to the sensor and the coaxial shield is connected electrically to the ring guard. see Figure 1.

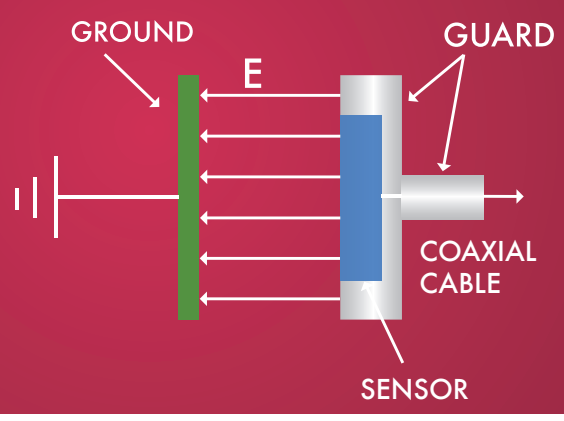

Figure 1: Distortion of electrostatic field minimized by guard ring.

Glass Making

Automotive windshields are manufactured in high volume 24 hours a day under very demanding environmental conditions. Capacitec HPC500 high temperature sensors are used to control the tooling geometry, which in turn assures that the windshields are produced with a consistent shape.

The sensors are exposed to 700°C in this glass molding operation. The sensors are also required to survive daily thermal shock cycles from 25°C to 700°C. Laser technology sensors were tried in this application in the past but could not survive the high temperature environment.

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CALIBRATION DATA SHEET

Customer :	Capacitec Sarl (MIN)
Job # :	60-32006
Date:	6/4/07
Std. Used :	38,116,156.00
Technician :	HT
Rack S/N :	4004-2500
Clock S/N :	5100C-0115
Drive S4/S5:	9/0 (5.50Vpp)

NOTES: Calibration Temp = 1000C
Calibration Points: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 115 Percent of fullscale.
3.1 KHz Filter

Start Gap	0.000
Stop Gap	0.200
Step Gaps	0.010
Start Output	0.000
Stop Output	10.000
Step Output	-0.500

Amplifier SN:	5100-0115	5100-0115
Probe SN:	HPT-75-25398	HPT-75-25399
Extension Cable:	EC-8959, 8957	EC-8959, 8957

Nominal GAP	Nominal OUTPUT	Ch.1 Output cal'd probe	Ch.1 Output record spare probe
0.000	0.000	0.000	
0.010	0.500	0.522	
0.020	1.000	0.962	
0.030	1.500	1.472	
0.040	2.000	2.002	
0.050	2.500	2.511	2.481
0.060	3.000	2.993	3.023
0.070	3.500	3.464	3.453
0.080	4.000	3.964	4.087
0.090	4.500	4.461	4.469
0.100	5.000	4.980	5.055
0.110	5.500	5.461	5.427
0.120	6.000	5.963	6.062
0.130	6.500	6.495	6.599
0.140	7.000	7.038	6.980
0.150	7.500	7.523	7.532
0.160	8.000	7.979	8.101
0.170	8.500	8.498	8.526
0.180	9.000	8.986	9.061
0.190	9.500	9.515	9.543
0.200	10.000	10.003	10.050
0.210	10.500		
0.220	11.000		
0.230	11.500		
0.240	12.000		

Figure 2: Capacitec HPT75 1,000°C calibration chart

Disc Brake Wear Analysis Sensors

Automotive brake engineers require verification of brake dimensions and to explain the dynamic physical characteristics of braking system components both on-vehicle and in the lab on dynamometers.

Using two HPC-150H sensors, one on either side of the disc, the following disc brake characteristics are measured at temperatures up to 600°C.

- Rotor run-out (TIR), Thermal expansion
- Rotor coning, Wobble
- Rotor thickness variation (RTV)
- Plate-to-plate orientation (V-ing, barreling)
- Caliper motion studies

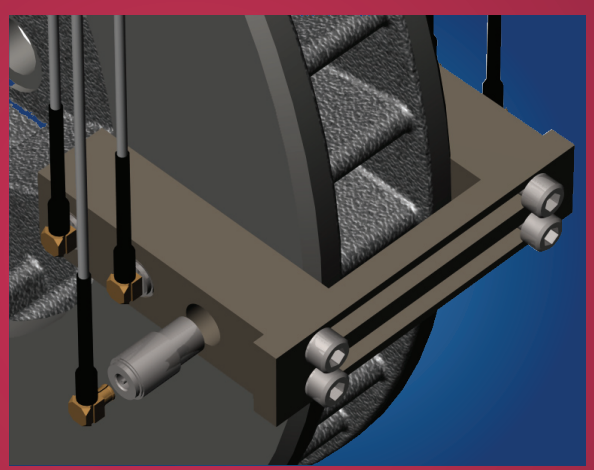

Figure 3: Sensors can be placed in pairs on either side of an automotive brake disc to dynamically monitor an assortment of performance parameters.

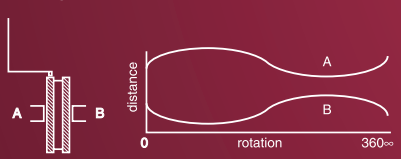

Figure 4: Mounting the probes opposite to one another will output the TIR on both sides of the rotor.

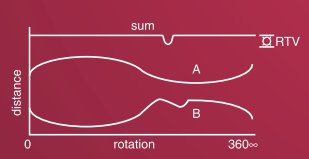

Figure 5: If there is a variation in the rotor thickness, there will be a corresponding change in the summed constant value output.

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Ring Position in an Engine Piston Head

Caterpillar Tractor came to Capacitec with a difficult measurement challenge - to dynamically measure motion in an engine piston, immersed in oil. They needed a very small, precise non-contact displacement sensor to be embedded into the moving piston with the sensor monitoring the up and down "flapping" motion of the surrounding piston rings operating at 250°C.

Capacitec was successful by installing two 4mm cylindrical style sensors with 1mm diameter coaxial cable (see Figure 6) that passed through a "grass hopper link" assembly to be taken out through the oil pan and then over to the on-board electronics.

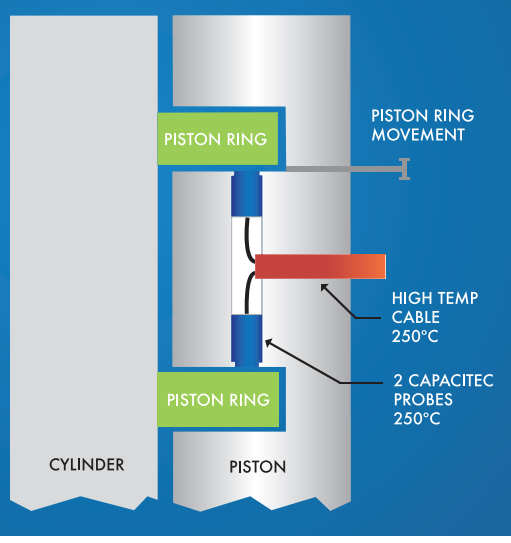

Figure 6: While fully immersed in engine oil, two high temperature Capacitec displacement sensors measure 50-micron movements in the piston rings for Caterpillar Tractor.

The Use of Non-Contact Thin Gap Sensors in Controlling Coater and Roller Gap Uniformity

Capacitive technology allows non–contact measurement of thin gaps from 0.10 mm to 1.0 mm. The use of this technology has resulted in the possibility of achieving repeatable coater gap uniformity <0.25 microns and roller gap uniformity <0.50 microns. Examples of thin gap coater control currently in use by world leaders are:

- Adhesive labels and tapes
- Photographic and medical films
- Wall panels and foam-based products
- Lithium-ion batteries
- Carbon composite materials

The full system includes sensor wands, special wand holders (see Figure 7), and signal conditioning electronics and software as seen in Figure 8.

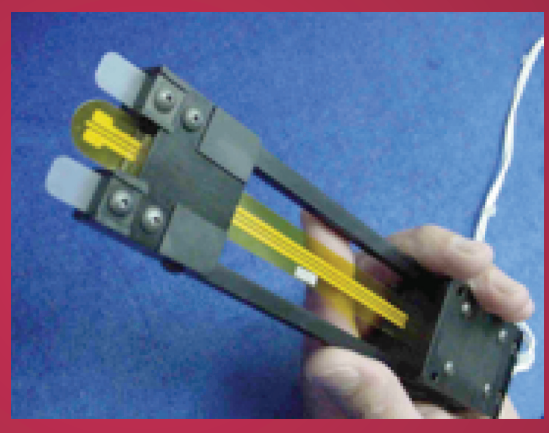

Figure 7: Custom wand holder with adjustable insertion length and slot guides

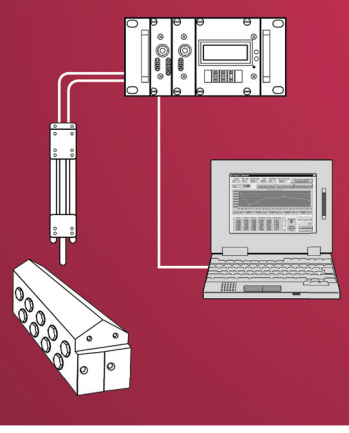

Figure 8: Complete 2 channel system with wand holder positioned to enter slot die gap

The Table Below Lays Out the Differences Between the Traditional Lab Based 5100 System and the New Simplified Gapmaster3 Portable "Electronic Feeler Gage" System.

Feature	Lab based system (System 1)	Shop floor system (System 2)	Benefits of shop floor system
Calibration / # of Channels	Full set of calibrations for up to 8 channels	1 or 2 calibrations	Simplified for shop floor use
Calibrated Range and Accuracy	Typical range from starting thickness is 250 microns = 10VDC Resolution: ± 0.025 microns Accuracy: ± 0.5 microns Repeatability: ± 0.25 microns	Typical range from starting thickness is 500 microns = 10VDC Resolution: ± 0.05 microns Accuracy: ± 1.0 microns Repeatability: ± 0.5 microns	Can measure more gaps with fewer sensor wands at lower sensitivity
Power	120/240 VAC	±15 VDC supplied by rechargeable portable battery pack	Portability, ability to reach limited access locations
Connection to Data Acquisition and Host Computer	Analog input to PC laptop based Capacitec Bargrafx software	• Built-in data logger • RS232 to host	Portability, convenience on shop floor

Conclusion

Capacitec presents specific examples of applications where capacitive technology has been adapted to measure very precise physical dimensions in extreme environments such as cryogenic to 1,000°C, radiation to 10^{11} Rads, magnetic fields to 5 Tesla, utilizing very small sensors with probe diameters down to 1.0 mm.

This technology has enabled large companies such as Group Schneider, Pechiney, EDF, Dupont, 3M, Avery, SNECMA, Rolls Royce, Jaguar, Ford, Renault, Siemens, Airbus, SAFT Battery and others to enhance their production methods to improve quality and reduce waste.

Capacitec is unique in the world as a supplier of exclusively capacitance based physical measurement sensors and systems. With an active Research and Development program, Capacitec will continue to offer new ways for process and manufacturing engineers, R&D and Quality Control engineers as well as Metrologists worldwide to enhance their dimensional measurement tool options to continue to improve the quality of their company's products and processes.

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