

# Noncontact Displacement Sensors in Automotive Manufacture

Advances in noncontact displacement sensors are bringing new levels of quality and efficiency to the research labs and assembly lines of automakers worldwide.

► Bryan Manning and Robert Foster, Capacitec, Inc.

Over the past decade, breakthroughs in sensor technology have improved the automobile both inside and out. Most consumers are aware of the benefits that sensors have contributed to automotive subsystems such as air bags, automatic braking systems, and load leveling systems.

Less obvious is the increasing role of sensors in R&D, QC, and manufacturing methods that are being driven by automakers' outsourcing certain subassemblies to Tier 1 suppliers such as Robert Bosch, Delphi, Visteon, and Continental Teves. These companies now supply complete suspensions, wheels, brakes, transmissions, and other components to Toyota, DaimlerChrysler, GM, Ford, and Volkswagen, among other global manufacturers. The automakers' role has also changed over the years from vertically integrated manufacturer to major assembly houses. Tier 1 suppliers are therefore subject to very stringent quality system requirements such as Q1 and QA9000, which place emphasis on building high-quality parts the first time, every time. As new QC practices such as in-process and 100% parts inspection become more commonplace, capacitive noncontact displacement and thin gap sensors are being used in an increasing number of locations throughout the automotive manufacturing process (see Figure 1).

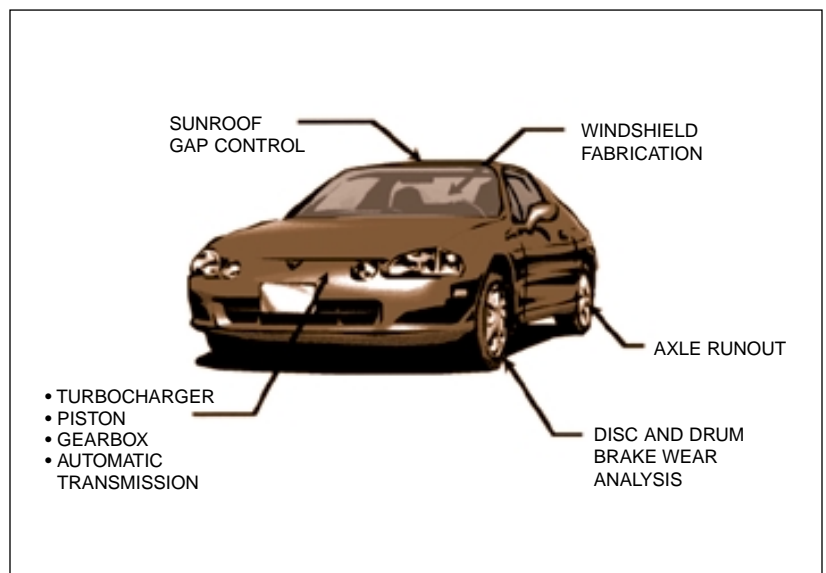
As component and subassembly dimensions shrink, the sensors used to measure them must also undergo miniaturization. Displacement sensors, for example, often must fit into locations with diameters <1 mm, where they measure gaps as small as 0.009 in. (0.23 mm). Other requirements include:

- Operating temperatures to 1832°F (1000°C)
- Overall diameter reduced to 0.004 in. (100 microns)
- Accuracy to 8 μin. (0.2 microns)
- Immunity to magnetic fields
- Response up to 200 kHz
- On-vehicle DC modular electronics

## Braking Systems (Disc and Drum)

The rugged modular electronics in Capacitec's new line of disc brake wear analysis sensors (see Figure 2) are capable of taking high-temperature (932°F, 500°C)

Figure 1. From engine piston and valve design, to braking and suspension system testing, noncontact displacement and gap measurement systems help engineers design better cars and trucks.



dynamic brake system measurements both in laboratory dynamometers and on the vehicles at test track facilities. By measuring displacement variables on a brake rotor in motion, data can be collected and analyzed to show several characteristics, such as:

- Rotor runout (TIR)
- Rotor thickness variation
- Rotor coning
- Thermal expansion
- Plate-to-plate orientation (V-ing, barreling)
- Wobble
- Ovality

The high-temperature and high-pressure conditions brought on by emergency braking or prolonged downhill deceleration can deform the brake drums used on heavy trucks. Brake malfunction can result from a drum's changing from its normal round shape to an oval configuration (see Figure 3). To perform onboard measurements of this phenomenon, Robert Bosch installed Capacitec's noncontact high-temperature brake probes. The sensor lead wires were routed through the wheel drums and connected to special electronics bolted to the outside circumference of the wheel. The electronics were made to survive the high g forces of high-speed rotation and ambient temperatures of  $>120^{\circ}\text{F}$  ( $49^{\circ}\text{C}$ ).

### Powertrains

Improving the designs and manufacturing methods for automotive engines and transmissions requires advanced displacement and gap sensors with these capabilities:

- Noncontact measurement
- Ability to withstand high temperatures

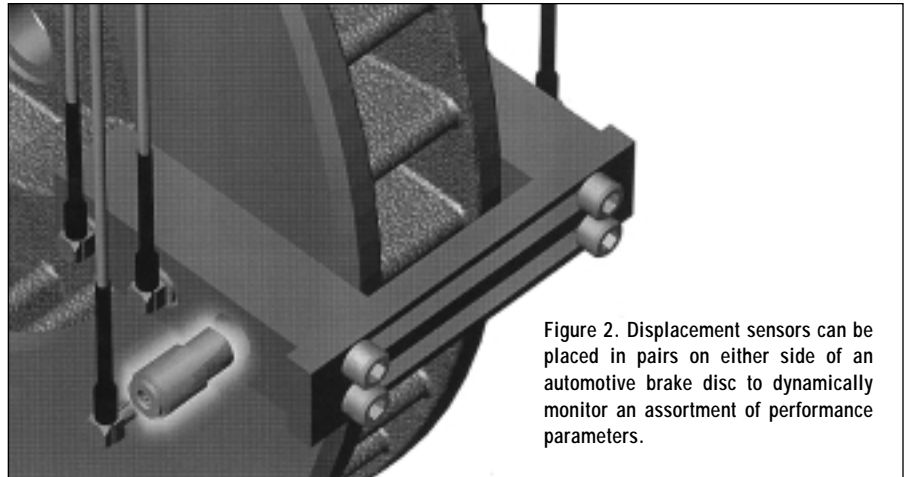


Figure 2. Displacement sensors can be placed in pairs on either side of an automotive brake disc to dynamically monitor an assortment of performance parameters.

and pressures

- No recalibration for variations in types of metal
- Operation in oil or transmission fluid
- Very small size for installation in tight spots
- Resistance to magnetic fields
- High-frequency response for tracking rapid rotation or axial movements

### Diesel Fuel Injection Systems

The closure position of the injection nozzle in large engines is instrumental in boosting efficiency as well as reducing engine noise. If the nozzle is not closed enough, fuel is wasted; too far closed, and the result is a "ringing" vibration that leads to premature nozzle failure.

This position measurement application is made more challenging by the high magnetic field environment created by the generator coils, along with the high-speed articulated motion of the nozzle stem that required a response of 30 kHz. The sensor probe that solved the problem is immune to

magnetic fields and has a specially matched magnetic case that allows it to function perfectly in high magnetic fields but at the same time not jeopardize the strength of the field powering the injector itself. The diesel engines thus tested and fine tuned meet federal fuel economy and emissions regulations, while at the same time benefiting from both reduced noise and increased mean time between failure.

### Ring Position in an Engine Piston Head

Caterpillar Tractor discovered through long-term engine testing that carbon buildup could actually seize the piston rings, allowing oil to pass into the combustion chamber and cause emission problems. The solution, measuring the motion of the oil-cooled pistons, required an accurate non-contact displacement sensor capable of operating while immersed in engine oil at a temperature of  $482^{\circ}\text{F}$  ( $250^{\circ}\text{C}$ ). To monitor the up-and-down "flapping" motion of the rings, Capacitec installed 4 mm dia. cylindrical sensors with a 1 mm dia. coaxial cable that passed through a "grasshopper link" assembly, out through the oil pan, and then over to the onboard electronics (see Figure 4).

AVL List GmbH in Graz, Austria, and Federal Mogul in Burscheid, Germany, carried out a joint experiment to study the piston ring dynamics of a utility wagon diesel engine. The aim of this study was to reduce the burning of engine oil and the concomitant exhaust gas emission, and to determine the best schedule for automotive maintenance. Placing capacitive probes on either side of each piston ring inside a reference piston allowed the investigators to track first and second piston ring axial motions (see Figure 5). In conjunction with complementary local pressure tracking, they were able to gather all the data rele-

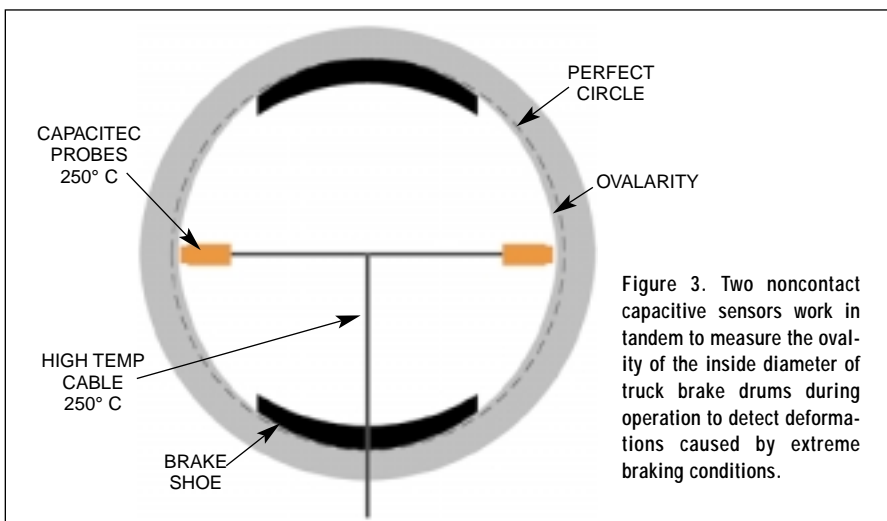


Figure 3. Two noncontact capacitive sensors work in tandem to measure the ovality of the inside diameter of truck brake drums during operation to detect deformations caused by extreme braking conditions.

vant to an understanding of piston assembly complex dynamics.

### Vehicle Assembly

Consistent and precise measurement of the various gaps around a vehicle's exterior surface is a difficult problem because of the wide variety of gap locations, each with its own requirements. The variables include:

- Different materials to be measured (e.g., metal, rubber, composites)
- Various contact/noncontact requirements (prevention of scratches)
- Wide range of gap sizes (0.23–10 mm)
- Wide range of target geometry (e.g., flat to radius, radius to sharp edge)
- Signal processing differences
- Instrument portability

Based on its experience in the aircraft industry, where smooth exterior surfaces are crucial to proper aerodynamics, safety, noise control, and fuel economy, Capacitec has developed a number of both contact and noncontact gap and flushness sensors for this application. The former are often preferable for target materials that are nonconductive or have unusual shapes; the latter are used when both sides of the target materials are conductive or where there is concern about finished surfaces, such as the painted exterior of vehicles at the end of the production line.

Controlling the flushness between a mounting bracket and the glass in an automobile sunroof is a good example. The curvature of the sunroof necessitates a varying amount of adhesive between the glass and the bracket. The way the process works is that the glass is first positioned into a fixture incorporating eight sensors around the sunroof. The sensors control the amount of epoxy distributed between the glass and

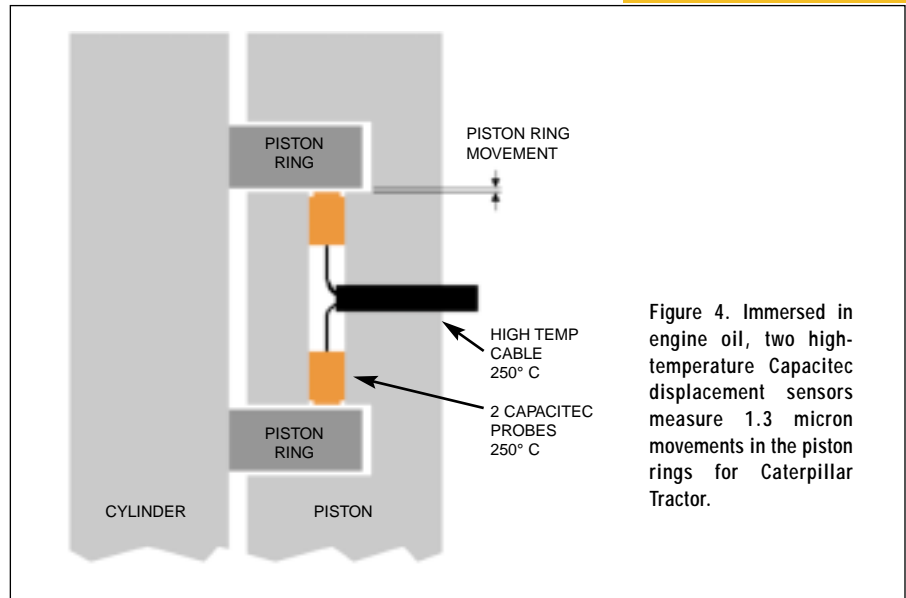


Figure 4. Immersed in engine oil, two high-temperature Capacitec displacement sensors measure 1.3 micron movements in the piston rings for Caterpillar Tractor.

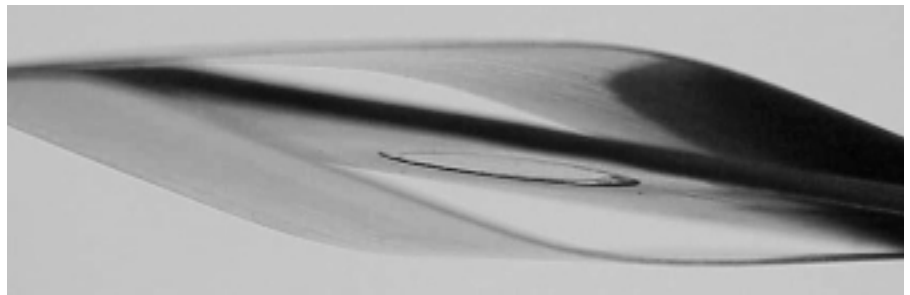


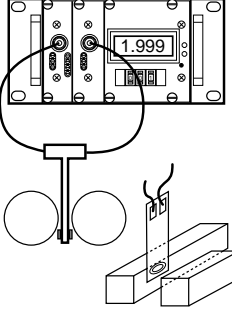
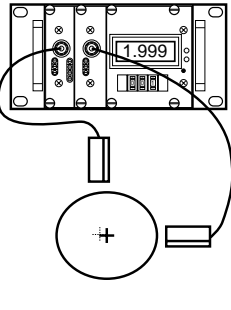
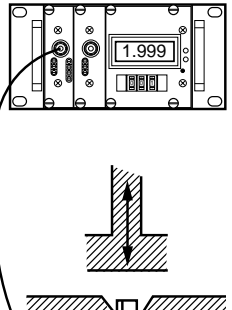
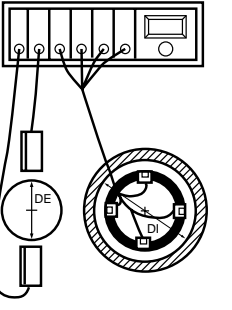
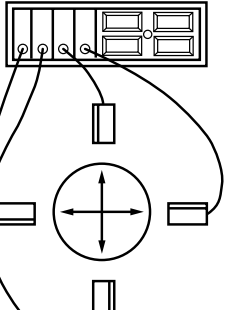
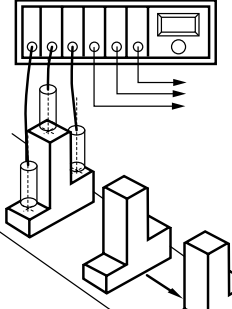
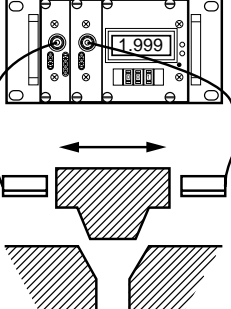
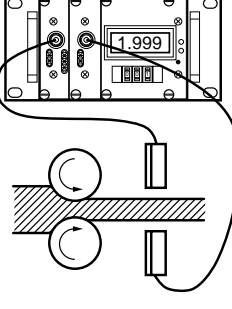
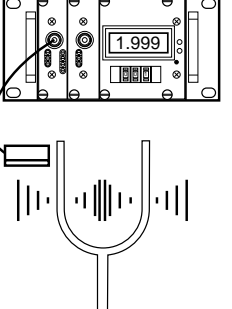
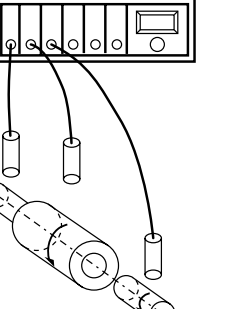
Figure 5. Two differential (back to back) noncontact sensors mounted in a 1.5 mm thick assembly are looking at the underside of two thin leaf springs that in turn contact a gap space with a range of 1.5–5.0 mm. Since there are two opposed spring forces, the wand assembly self-centers itself in the gap, almost doubling the measurement range of previous configurations.

bracket, ensuring a consistent geometry to each sunroof. This gap and flushness measurement system allowed General Motors to achieve a  $\pm 0.004$  in. (100 micron) tolerance on a gap of 0.060 in. (1.5 mm). The finished sunroofs were flush against the top of the vehicle, dramatically reducing noise while contributing to aerodynamics and fuel economy. ■

**Bryan Manning** is a Technical Marketing Consultant, B&D International LLC, 1050 Brook Rd., Milton, MA 02186; 617-698-1123, bryanm@bu.edu.

**Robert Foster** is Director of Engineering, Capacitec, Inc., PO Box 819, Ayer, MA 01432; 978-772-6033, fax 978-772-6036, sales@capacitec.com.

# TYPICAL APPLICATIONS

 <p>Two sided sensor Gap measurement</p>	 <p>Eccentricity/ Out of round profile</p>	 <p>Position &amp; Displacement</p>	 <p>Inside/Outside diameter</p>	 <p>Alignment (one or two axes)</p>
 <p>Dimensional measurement</p>	 <p>Position control</p>	 <p>Thickness measurement</p>	 <p>Vibration measurement (amplitude and frequency)</p>	 <p>Concentricity</p>

 **Capacitec**

US HEADQUARTERS  
 Capacitec, Inc.  
 87 Fitchburg Road  
 P.O. Box 819  
 Ayer, Massachusetts 01432  
 USA  
 978-772-6033  
 FAX: 772-6036  
 email: sales@capacitec.com

EUROPEAN HEADQUARTERS  
 Capacitec  
 16, rue Séjourné  
 94044 CRETEIL cedex  
 FRANCE  
 33 1 43 39 48 68  
 FAX: 49 80 07 49  
 email: eurosales@capacitec.com