Capacitec®

NONCONTACT DISPLACEMENT SENSORS IN AUTOMOTIVE MANUFACTURE

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

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 automatic braking systems, muffler noise reduction, 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 Bosch, Delphi, Brembo and Continental Teves. These companies now supply complete suspensions, wheels, brakes, transmissions, and other components to GM, Ford, Toyota, Stellantis, 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 industry standard quality system requirements 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 spring contact gap sensors are being used in an increasing number of locations including EV Motor assembly in the automotive manufacturing process *(see Figure 1)*.

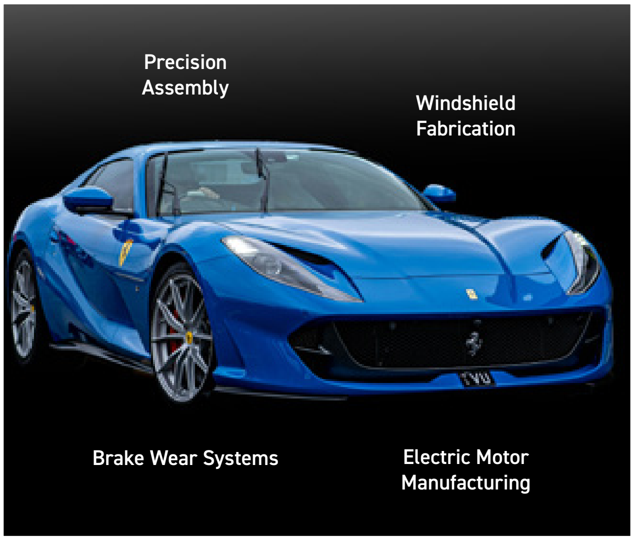

FIGURE 1. Braking and suspension system testing used for cars and trucks, high temperature windshield forming, electric motor alignment, and hidden air gap measurement in chassis assembly.

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 very thin sensor access. For example, they must fit into locations with air gaps as small as 0.008 in. (0.21 mm). Other requirements include:

- Standard Product Operating temperatures for Brake Systems to 1600°F (870°C)
- New gap sensors that are 0.004 in. (100 microns) thickness
- Capacitive Sensor Immunity to magnetic fields
- Response up to 20 kHz
- Custom On-vehicle real-time modular electronics

Braking Systems (Disc and Truck Drum)

The rugged modular electronics in Capacitec's new line of disc brake wear analysis sensors (see Figure 2) are capable of measuring high-temperature (1200°F, 648°C) displacement for dynamic brake system motions 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, 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°F (49°C).

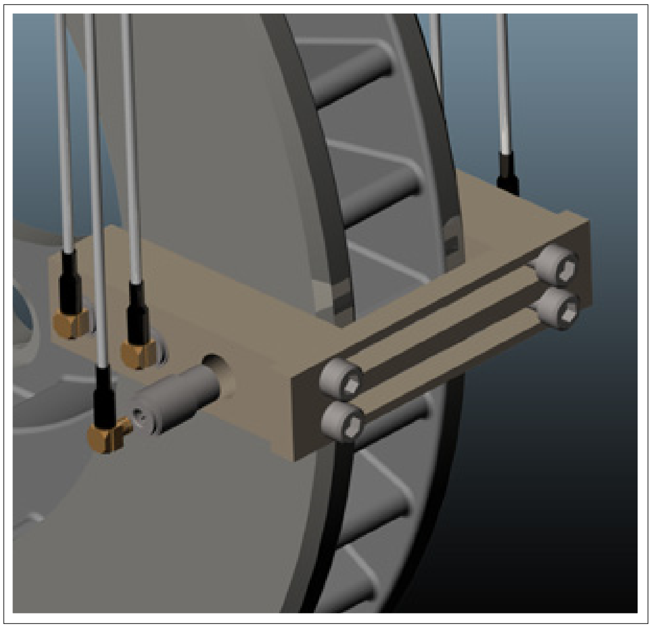

FIGURE 2. Displacement sensors can be placed in pairs on either side of an automotive brake disc to dynamically monitor an assortment of performance parameters including incidental brake pad contact wear with the rotor.

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 and pressures
- No recalibration for variations in types of metal
- Operation in 100% (no air) 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

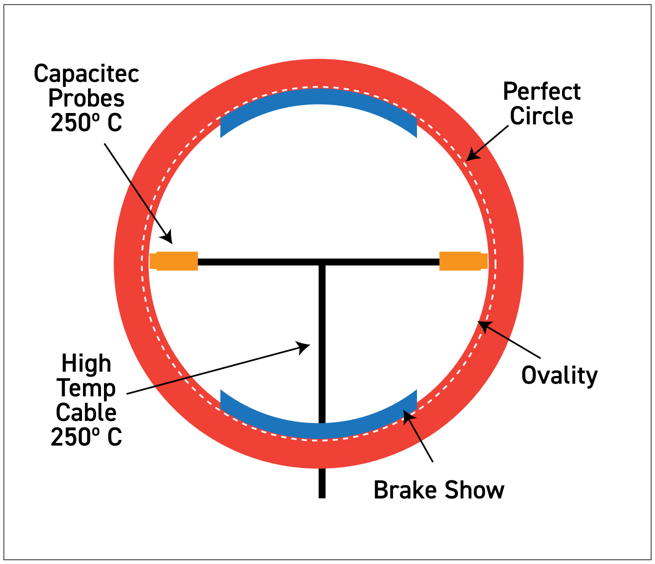

FIGURE 3. Two noncontact capacitive sensors work in tandem to measure the ovality of the inside diameter of truck brake drums during operation to detect deformations caused by extreme braking conditions.

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 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. These tests utilize calibration fluid for safety.

Gap Measurement: Precision Coating for EV Battery Manufacturing and Electric Motor Production

Capacitive gap sensors are pivotal in the design and manufacture of precision electric motors for use in electric vehicles (EVs) of all types. Gap measurement solutions using non-contact and contact (spring contact gap wands) measurement techniques to enhance accuracy and reliability are deployed throughout the design and production of EV motors.

Capacitec's non-contact sensors operate on the principle of capacitance, measuring gaps between conductive surfaces to provide gap monitoring which is crucial for both Slot Die and roll-to-roll quality control. Coater gaps achieve resolutions below one micro-inch between setting the width of the slot gap and the thickness of the coating material, it is critical for manufacturers to set a very uniform gap along the full length of the coater die.

EV Battery performance consistency depends significantly on the uniformity of electrode layers produced using these coating techniques. Battery electrodes require precise uniform thickness to optimize electrochemical reactions which ensures consistent ion diffusion rates. Uniformity in coating thickness is essential for meeting regulatory standards for safety, durability, cycle-life performance criteria.

Rotor Stator Gap Physics

Today's EV applications place increasing demands on electric motor efficiency. The air gap plays a vital role in the magnetic interaction between the rotor and the stator. A smaller air gap typically enhances the magnetic attraction force, as magnetic force is inversely related to the square of the distance between the rotor and stator. Conversely, an increased air gap weakens the magnetic field strength, leading to reduced operational efficiency. For optimal performance, it is generally advantageous to minimize the air gap to enhance torque generation and reduce hysteresis losses within the stator and rotor.

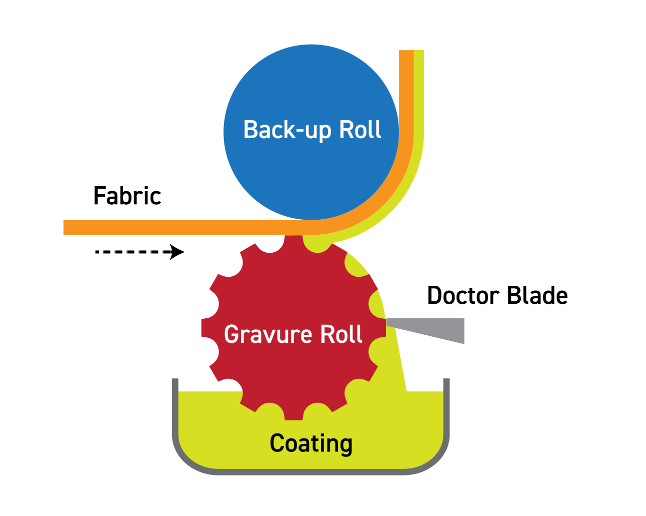

FIGURE 4. Roll-to-Roll production methods ensure consistent uniform coating thickness by controlling the gap and creating a consistent ion diffusion rate required for reliable EV battery operation

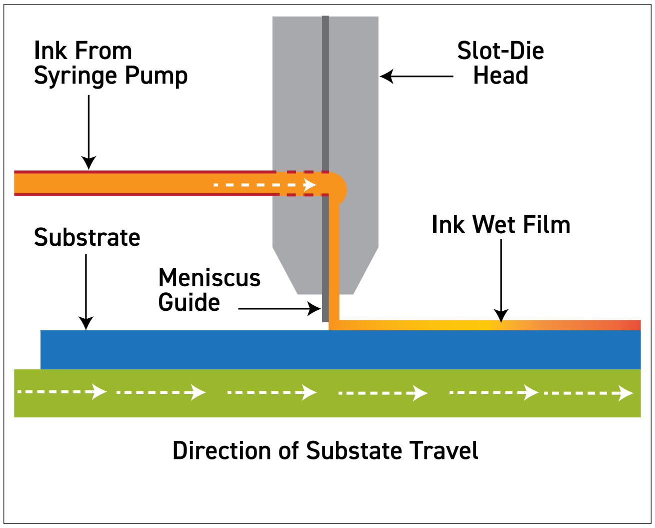

FIGURE 5. Maintaining a uniform Gap across the entire Slot Die is vital to producing high quality, reliable Battery electrode.

Assembly of Electric Motors – Concentric Alignment

In the context of electric motor manufacturing for EVs, capacitive gap sensors are used by designers, engineers and production personnel to accurately center the rotor assembly, which is critical for optimizing performance and minimizing performance losses. Capacitec's gap sensors ensure that the spacing between the stator and rotor is uniform, and remains within specified tolerances, thereby enhancing the motor's efficiency and reliability. By incorporating capacitive gap sensors, manufacturers can implement more rigorous quality control measures, leading to higher quality, more efficient electric motors that meet the demanding requirements of modern EV applications.

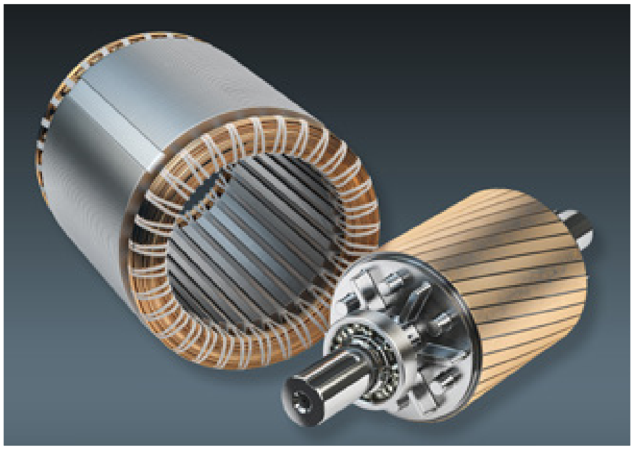

FIGURE 6. Rotor Stator Gap Physis require that the gap be as uniform (concentric) and narrow as possible for optimal efficiency.

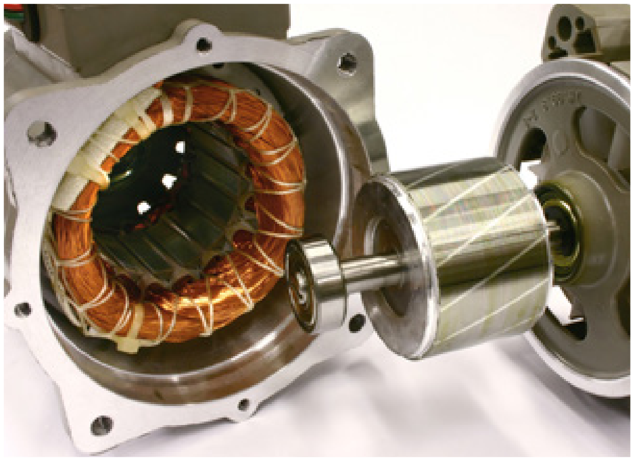

FIGURE 7. EV motors require increased precision in the assembly process in order to maximize transfer of energy to the powertrain.

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 bracket, ensuring a consistent geometry to each sunroof. This gap and flushness measurement system allowed General Motors to achieve a ±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.