Advanced Motorsport Sensing: Texys Explores FBG and Capacitive Technologies for Measuring What Was Previously Unmeasurable

From embedded optical fibers inside carbon structures to non-contact turbocharger blade-clearance measurement at extreme temperatures, Texys America and Fogale Sensors examine how advanced sensing technology is opening new areas of race-car data acquisition.

As race teams push deeper into data acquisition, the challenge is no longer simply collecting more channels. Increasingly, it is about measuring physical behavior in places where conventional sensors are difficult—or sometimes impossible—to use.

During a recent EPARTRADE Race Industry Now technical webinar, “Advanced Sensing for Motorsport: Capacitive & FBG (Fiber Bragg Grating) Technologies,” Texys America presented two advanced measurement technologies capable of addressing precisely those environments.

Ben Hewitt, Commercial Engineer – Motorsport at Texys America, and Julien Chenaux, Product Manager with Fogale Sensors, examined Fiber Bragg Grating optical sensing and high-precision capacitive measurement, including applications ranging from embedded composite strain measurement and aerodynamic load analysis to turbocharger blade monitoring, ride-height measurement, brake wear, electric-motor analysis and liquid-hydrogen fuel systems.

The session was hosted by noted NHRA crew chief Jim Oberhofer.

Hewitt, who joined Texys America after serving as Manager of Systems Engineering at McLaren IndyCar, noted that increasingly sophisticated engineering capabilities are spreading throughout motorsports.

“We've seen a huge increase in the engineering capabilities that a lot of teams are bringing to the track,” Hewitt explained, including technologies that were once largely restricted to the highest levels of professional racing.

Measuring Strain With Light: Fiber Bragg Grating Technology

One of the most intriguing technologies presented was Fiber Bragg Grating, or FBG, sensing.

Hewitt described the concept in straightforward terms: strain gauges that use light.

The technology starts with an optical fiber containing microscopic gratings created through a laser process. These gratings reflect very specific wavelengths of light. When the fiber experiences mechanical strain or changes in temperature, the wavelength reflected by the grating shifts.

An interrogator sends light through the optical fiber, detects those wavelength shifts and uses decoding algorithms to translate them into meaningful strain or temperature measurements that can then be passed to the vehicle's data-acquisition system.

One significant advantage is wavelength multiplexing.

Multiple sensing points can be incorporated along a single continuous optical fiber, with each grating responding at a different wavelength. A team could therefore potentially measure strain at several locations—and temperature at others—using the same fiber and interrogator.

For race-car engineers trying to increase instrumentation without adding excessive wiring, electronics or aerodynamic disruption, that architecture presents some compelling possibilities.

Sensors Embedded Inside Carbon-Fiber Components

Perhaps the most interesting motorsport application is the ability to integrate the optical fiber directly into composite structures.

The fiber is extremely small—Hewitt compared it visually to a human hair—and can potentially be placed between layers of carbon fiber during manufacture.

A race-car wing, for example, could contain its own embedded sensing structure.

Instead of attaching external strain gauges and associated hardware to the finished component, engineers could potentially measure structural strain or temperature from within the composite itself.

That opens possibilities for measuring loads and structural behavior in chassis components, bodywork and aerodynamic devices while minimizing disturbance to the component or surrounding airflow.

It also eliminates electronics at the measurement point.

With conventional strain-gauge installations, amplifiers and associated electronics can create packaging difficulties, particularly in areas exposed to high temperatures or where aerodynamic cleanliness is critical. With an FBG system, the sensing element itself is optical.

There is also no electrical power at the sensing location.

Hewitt offered a very motorsport-specific example: if an instrumented front wing were damaged or torn from the car, there would be no sensor power or ground circuits at the wing to short and potentially create downstream electrical-system problems.

FBG sensing is also inherently immune to electromagnetic interference, making it attractive around electrically noisy environments such as high-power injector drivers and other electronics.

Additional advantages discussed included resistance to harsh environments, low optical losses, high fatigue durability, long-term accuracy and the ability to place sensing elements in recessed or otherwise difficult-to-access locations.

Although FBG technology has already been deployed in aerospace, industrial and infrastructure applications—including structural monitoring of wind-turbine blades—Texys sees significant potential for bringing the technology further into motorsports.

The company is also developing a more easily embedded interrogator specifically aimed at racing applications.

Capacitive Sensing: Measuring Distance Without Contact

Chenaux then shifted the discussion to capacitive sensing, an area in which Fogale Sensors specializes.

The underlying principle is relatively simple.

An electrode within the sensor and a conductive target form a capacitor. Because electrical capacitance is directly related to the distance between the two, extremely small changes in distance can be determined by accurately measuring changes in capacitance.

The result is non-contact displacement measurement capable of extremely high resolution.

According to Chenaux, capacitive technology can detect distance variations down to nanometer-scale resolution under appropriate conditions, while also providing sufficient bandwidth to measure rapidly vibrating components.

Because the measurement is non-contact, there is no mechanical wear between the sensor and the component being measured.

That becomes particularly important when attempting to analyze extremely fast rotating components.

Inside the Turbocharger: Blade Tip Clearance and Blade Tip Timing

One of the most developed motorsport applications presented was turbocharger analysis.

Fogale's KappaBlade system uses capacitive sensors positioned toward the rotating turbocharger blades to measure two important parameters: Blade Tip Clearance (BTC) and Blade Tip Timing (BTT).

Blade tip clearance is the gap between the rotating blade tip and surrounding housing.

Reducing that clearance can improve turbocharger efficiency, but there is an obvious mechanical limit: reduce the gap too far and the blade can contact the housing.

The capacitive sensor detects each blade as it passes. The amplitude of the resulting signal is used to determine blade tip clearance.

The timing of that signal provides another piece of information.

By precisely analyzing when individual blades arrive at the sensor, engineers can perform Blade Tip Timing measurements, which can be used to investigate blade deflection, vibration and resonance behavior.

That gives turbocharger manufacturers and race engineers a method of comparing real-world component behavior against simulation and design calculations.

The system can acquire both blade tip clearance and blade tip timing for individual blades on every revolution—even as rotor speeds and acceleration rates become extremely high.

Fogale's acquisition architecture can accommodate as many as 12 conditioning modules and sensors simultaneously.

For turbocharger development, that represents an enormous amount of high-speed information about what is occurring inside a component that is otherwise extremely difficult to observe dynamically.

Extreme Temperature Without Sensor Cooling

The environment makes the measurement capability even more notable.

Chenaux said Fogale's capacitive sensors can operate at temperatures up to 2,552 degrees F without sensor cooling, allowing installations on the hot side of turbocharger applications and in other severe thermal environments.

The sensors are also designed for long-term measurement and are not affected by electromagnetic interference, dust or surface reflection.

Rather than attempting to force a standard sensor into every application, Fogale frequently develops application-specific sensing configurations. Chenaux noted that the company has created more than 400 sensor designs as it adapts the measurement system to individual packaging and performance requirements.

That ability to customize becomes especially relevant in motorsports, where available space, temperature, vibration and component geometry can vary dramatically from one installation to another.

Measuring Ride Height Directly Against the Racetrack

Capacitive technology also creates an interesting approach to one of racing's most important measurements: ride height.

Instead of inferring chassis height exclusively through suspension-position sensors, a capacitive sensor can be mounted underneath the vehicle and use the track surface itself as the target.

The system then continuously measures the physical distance between the car and racetrack.

For cars in which aerodynamic performance is highly sensitive to floor height, pitch and platform control, direct non-contact measurement of the vehicle's relationship to the track could provide extremely useful development data.

Chenaux said capacitive sensors can similarly be integrated directly into suspension components to measure suspension travel.

During the Q&A, he added that the system is capable of measuring vibration at frequencies up to approximately 20 kHz, enabling real-time observation of very small component movements in highly dynamic environments.

Brake Disc Wear, Brake Torque and Rotating Machinery

The technology's potential applications extend throughout the race car.

Using two opposing capacitive sensors, engineers can measure brake-disc thickness and therefore monitor disc wear.

Brake torque can also be investigated indirectly by measuring minute deformation of the brake caliper under load.

For rotating systems, multiple sensors can measure shaft runout, eccentricity, alignment and vibration without mechanical contact.

Electric-motor rotor expansion is another potential application—particularly relevant as electrified powertrains become increasingly common in Formula E, hybrid racing programs and other advanced vehicle-development environments.

The common thread is the ability to quantify very small movements without physically loading or contacting the component being measured.

Measuring Liquid Hydrogen

At the opposite end of the temperature spectrum from turbochargers is another emerging motorsport application: liquid hydrogen.

Chenaux said Fogale is seeing increasing demand associated with LH2 tank development for transportation and motorsport applications.

The company can provide flexible or rigid capacitive sensing elements for determining liquid-hydrogen level inside a tank.

This introduces an entirely different set of engineering challenges. Liquid hydrogen must be maintained at cryogenic temperatures, while a racing vehicle also subjects the tank and its contents to acceleration, braking, cornering and severe slosh.

Fogale's high-bandwidth capacitive measurement technology is intended to maintain useful level information despite that fluid movement.

It is a striking demonstration of the technology's operating range: essentially the same fundamental measurement principle can be adapted from cryogenic liquid-hydrogen systems to turbocharger environments exceeding 2,500 degrees F.

Invisible Sensors Inside the Cockpit

Chenaux also presented what could become another interesting area of race-car development: capacitive “smart skins.”

Extremely thin sensing elements can be integrated behind plastic, textile, foam and other surfaces rather than being exposed as conventional switches or sensors.

Within a racing cockpit, that could allow sensors to be integrated into the steering wheel, dashboard, doors or even the driver's seat.

Depending on the configuration, the system can detect presence, proximity, pressure and direction of movement without requiring a camera.

Embedded into a seat, for example, the technology could potentially monitor driver presence, position or posture.

More broadly, sensors could be incorporated into different parts of the chassis to measure extremely small changes in the position of one structure relative to another, providing engineers with another means of studying how the race car physically behaves under load.

From Aerospace to Motorsport—and Back Again

An important theme throughout the discussion was the exchange of technology between racing and other highly demanding engineering industries.

Texys Group technology is used across motorsport, aerospace, automotive, marine, energy, railway and other applications.

In some cases, racing acts as the proving ground.

As Hewitt explained, being able to tell an industrial customer that a sensor is “race-proven” provides meaningful validation because motorsport exposes electronics and instrumentation to extreme temperature, vibration, acceleration and environmental conditions.

In other cases, the technology flows in the opposite direction.

FBG sensing, for example, has developed through aerospace, energy and infrastructure applications and is now being adapted to the unique requirements of racing.

That crossover is particularly significant as motorsport engineers search for measurements beyond the capabilities of conventional vehicle instrumentation.

The objective is not simply adding more sensors.

It is gaining access to physical behavior that previously could not be measured accurately without interfering with the component being studied.

Whether that means monitoring a turbocharger blade traveling only fractions of a millimeter from its housing, measuring chassis movement against the racing surface, embedding a strain sensor inside a carbon-fiber wing or determining what is happening inside a cryogenic hydrogen tank, the next frontier in race-car data acquisition increasingly involves making the invisible measurable.

And as Oberhofer observed during the discussion, every new generation of sensing technology gives race engineers another opportunity to better understand what the car is actually doing. For motorsports, that understanding has always been where performance begins.

For more information, **watch the full webinar here.**