In full flow

Leading fuel flow meter producer Sentronics talks us through the intensive product development programme that has helped it scoop the Formula 1 supply contract for 2018/19

By GEMMA HATTON

Motorsport engineers are notorious for going to any length to gain performance. For example, the latest fuel flow meter (FFM) variants can achieve accuracies of better than one per cent and yet teams have still invested time and money to find a small advantage here. In some cases they've purchased several fuel flow sensors for testing and established which one under-reads the most. By fitting this they can squeeze an extra few tenths of a per cent of fuel into the engine, while still complying with the regulations. It's quite clear, then, why these devices need to be as accurate as possible.

Mechanical flow meters traditionally use an impeller located between the inlet and outlet of a pipe. The flow of the fluid spins the impeller and the number of revolutions are counted; measuring the flow rate. However, in a racing engine a mechanical system cannot keep up with the highly dynamic changes in flow rate caused by moving from zero to maximum throttle within a fraction of a second.

'An impeller has mass by its very nature,' says Neville Meech, director of Sentronics. 'As a result of this, when the impeller attempts to rotate at a rate matching fuel consumption the inertial effects will cause the device to overshoot and then undershoot, resulting in immediate measurement errors.'

Solid state

'The other problem with most mechanical devices is they do not respond well with rapid reverse flows,' Meech adds. 'When the brakes are applied and the engine revs drop, typically a water hammer effect is momentarily created within the fuel system due to the fuel column coming to an abrupt stop. An impeller flow meter cannot stop quickly enough, and then reverse its direction, so once again you introduce significant errors. These fundamental problems were identified many years ago during potential technology assessments and this is why the core technology at the heart of our fuel flow meter is solid-state.'

Solid state essentially means no moving parts and, in principle, the most suitable non-invasive alternative to measure fuel flow is ultrasonic technology. The challenge, however, was to take the concept of ultrasonic flow measurement that had traditionally been used in large oil and gas pipelines, and develop an accurate meter which could then be packaged for use on a racecar.

'At the time, highly accurate ultrasonic devices were limited to six-inch pipe diameters and greater, and the technology was not suited or robust enough for motorsport,' says Meech. 'Some said that it would never work, especially as we needed to achieve measurements within +/- 0.25 per cent error, which was at least four times better than any similar sized ultrasonic equipment could achieve back then. As engineers we questioned the scientific reason behind this – was it because no one had ever tried to develop it before? Because if so, we wanted to pioneer the technology to make it happen.' The latest Sentronics Fuel Flow Elite Sensor, which will be used in Formula 1 next year, is specified to achieve accuracies of +/- 0.25 per cent of reading across operating conditions, which conforms to the technical specification set out by the FIA since 2014. Mission accomplished, then. But how?

Quickened pulse

Located at either end of a thin tube are two piezoelectric transducers. These are effectively ceramic discs, suspended in a fuel resistant housing, which convert electrical energy into ultrasound pulses. In principle, a pulse is sent from one transducer to the other, in the direction of flow. This is then followed by another pulse sent back to the original transducer in the opposite direction. With the distance between transducers known, the time of flight of both pulses is measured and then subtracted to determine the velocity. As the tube diameter is also known, the flow rate of the fuel can be easily calculated.

'One problem with ultrasonic flow measurement is its fundamental principle is volumetric, this means to calculate mass flow accurately a density measurement is required. Very accurate density measurement is typically

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Low flow technology could be particularly useful in a sportscar series that requires refuelling

Sentronics is an industry leader in the development and manufacture of solid state ultrasonic fuel flow meters

performed using a Coriolis or tuning fork densitometer, which just don't work when subjected to vehicle NVH (Noise, Vibration and Harshness). Hopefully this will change as densitometer technology advances but the best option at present is to calculate density using a very accurate temperature measurement, and calculate density based on fuel samples which have had the density properties very accurately measured under laboratory conditions,' explains Meech. 'If you were 3degC out on temperature you could end up with a 0.5 per cent error within the sensor.'

Once the temperature of the fuel has been identified, the necessary look-up is performed and mass flow rate is calculated, which is the final figure all the engineers are after.

But what is the optimum strategy for sending the ultrasound pulses to achieve the highest accuracy? How often and how quickly should the signals be sent? And is it better to send the signals together or one at a time?

'The biggest complexity comes when you have to measure the flow rate faster than 200 times a second, which is generally the industry standard for ultrasonic flow meters,' Meech says. 'Acoustic energy takes time to decay away, less time between measurements means you need techniques and algorithms to deal with any unwanted ultrasonic signals that have not had time to fully decay. Our patented technology allows us to achieve highly accurate time of flight measurements even with all these interfering signals being present.

'It was established early on in development that the industry standard measurement rates were just not going to give accurate readings for on-vehicle applications, we needed to

'We needed to increase the measurement rate, to sample the flow rate in excess of 2200 times a second'

increase the measurement rate to sample the flow rate in excess of 2200 times a second to ensure that any vehicle or engine borne vibration exerted into the fluid column is measured correctly and not aliased.'

A further consideration is the type of materials used. As ever, it's crucial to minimise weight, but, for once, composite components may not be the answer. By using a range of materials, the different rates of expansion with temperature can become geometrically complex and result in introducing a further source of error and potential leak paths. Therefore, to ensure consistent device-to-device repeatability it is more effective to construct the sensor out of one type of material, rather than using the algorithms or calibration to compensate for different material expansion rates. In the case of Sentronics, the fuel flow sensor is made purely from a single metallic material, avoiding the need for any plastic parts.

All materials used also have to be compatible with all the different variants of fuel including ethanols, methanols and additives. This is particularly important for any rubber seals because when rubber is impregnated with fuel it can increase in stiffness, which can effect the ability to transmit the ultrasound pulses.

Another challenge is repeatability. 'It's difficult enough to make one *perfect* sensor which achieves the required high levels of precision, but the bigger challenge is making that repeatable, when you have to make 100, 500, or more,' Meech says.

'Ultimately, our aim has been to create a technology where the sensors native response to a flow rate stimulus is consistent from meter to meter. This has been our biggest achievement over our four year development and we look forward to the devices becoming commonplace in motorsport.'

Toyota practices changing the FFM, located behind driver's door on LMP1 cars. Flow meters measure average flow in WEC

Calibration methods

Any sensor supplier may state impressive accuracy, but how do they know the measurement readings are actually true? This is where calibration comes in. Calibration is defined as a series of interrelated measurements and operations which compare the reading of a device to a traceable standard. In this way, a relationship is established between the quantity measured by the device and the measurement of the same quantity by the reference.

For regulatory use, each sensor is measured against a known stimulus and, once adjusted, the combined measurement uncertainty cannot exceed +/-0.25 per cent of flow rate across a range of flow conditions that will

All the GT and prototype cars in IMSA will carry a fuel flow meter next season because, according to the series, the teams' fuel consumption reporting has been 'questionable at best'

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Top left: Sentronics has won the tender to supply the Formula 1 grid with its fuel flow meter for 2018

Above: The front half of the fuel flow meter contains the tube where the ultrasound pulses are transmitted and the rear half houses the electronics

Left: The modular design of Sentronics' FFM has allowed it to adapt the technology to both low flow and high flow applications

A brief history of FFM

While Sentronics was not the original supplier of the fuel flow meter (FFM) back in 2014, it is worth noting here that the introduction of the technology into Formula 1 and the World Endurance Championship was controversial.

The original plan was to use the restriction of fuel to balance cars, rather than an air restrictor which had been common for many years.

While the FIA required an accuracy of +/-0.25 per cent of reading, and this was largely achieved, some teams identified a problem with aliasing, where information was being lost due to under-sampling of the flow rate. At the Australian Grand Prix in 2014, Red Bull Racing attempted to prove that its measurements were more accurate than that of the FFM, but it lost its case as the FFM was judged to be the tool by which the FIA measured the rate of flow.

The aliasing issue remained a problem for some teams, despite numerous upgrades from the original supplier, but now will finally be eradicated with the introduction of the Sentronics 2018 FFM.

In the WEC, meanwhile, an accuracy problem was identified and unfortunately amplified in the diesel engine, where flow and return sensors were required. With its high diesel return temperatures the Audi R18s suffered with accuracy. The FIA subsequently homologated a high-temperature sensor to particularly help the diesel engines, which was developed and supplied by Sentronics. Unfortunately, these sensors never saw action, as Audi quit the WEC before they were used.

When it was in the WEC Audi's R18 suffered with fuel flow meter accuracy problems caused by the high diesel return temperatures

Cash flow

Today, the sensors are infinitely more accurate than in 2014, but having improved the accuracy, the challenge now is to reduce the costs to make the technology more accessible (and useful) to other race series throughout the world. With this in mind Sentronics says it has been able to reduce the price of the sensor itself, due to an increase in demand, and is now actively offering the benefits of the technology to lower formula series.

be experienced on the vehicle. This is a very thorough process and tests conformity across a range of temperatures and flow-rates.

Low flow

The concept behind Sentronics' fuel flow technology has proven so successful that both low flow and high flow variants have been developed. 'Low flow is a very difficult parameter to measure accurately due to your zero flow error becoming the overriding source of inaccuracies,' explains Meech. 'For example, if you have one per cent error in your measurement and you are measuring flow rates of five litres/min then there is plenty of difference in ultrasonic pulse timings to allow for small errors. However, if the flow rate is four ml/min, which is less than a teaspoon of fuel per minute, one per cent error is +/-0.04ml/min, which equates to timing differences of sub pico second levels. This is an incredibly difficult task.'

For reference, in 2014 the new F1 power units were using approximately 2.7 litres/min and with the improvements in fuel consumption now have flow rates of around 1.9 litres/min.

Low flow measuring devices have become essential for both OEMs and automotive testing companies because WLTP (Worldwide Harmonised Light Vehicle Test Procedure) and RDE (Real Driving Emissions) tests are now mandatory in the EU for new vehicles. This focus on emissions testing requires companies to publish figures such as fuel consumption, so being able to very accurately monitor the amount of fuel going into the engine has now become even more of a necessity.

Strategic measures

In motorsport terms, low flow technology could be particularly useful in series such as IMSA, and other sportscars series that require refuelling. With the ability to measure low flow conditions with +/- 0.25 per cent accuracy, when off throttle or mid-corner, the engineers can get a much better understanding of the overall fuel consumption figures which can in turn help them to strategise their pit stops more effectively. 'I think we're going to see a mind-set change with this technology,' Meech says. 'The feedback from those who have tested with this sensor is extremely positive because they can change their thinking of the fuel load they need to carry, when they carry it, and when is the best time to refuel.'

One of the secrets behind the development of the low flow variant is the modular design of the original Sentronics fuel flow meter. The sensor itself is built in two halves; the front half houses the tube and the piezoelectric transducers, with the other electronic components situated in the back half. Therefore, the tube for the low flow version could be redesigned and then bolted on, without Sentroncis having to modify or interfere with the electronics housing.

Going with the flow

Josef Newgarden won the IndyCar title for Penske driving with a fuel flow meter, which helped the team with its strategy

Corvette has used FFMs this season; it maintains visibility to the team on fuel consumption during full course cautions

Restricting fuel flow is just one application for the fuel flow meter – as used by the FIA which regulates either maximum flow (in Formula 1) or average flow (WEC) – but there are other uses, as Corvette and Penske have discovered in US racing.

Fuel consumption is relatively well-known under normal conditions, but behind the safety car it's more of a challenge, and teams are left to calculate consumption at reduced speed. Over the past 20 years, more than a quarter of the laps at the Indy 500 have been run under caution, leaving teams relatively blind to their actual consumption figures.

But with the fuel flow meter transmitting live information back to the pits, teams are completely aware of when they need to stop for fuel, rather than relying on ECU injector data alone, and that has led to some interesting decisions from teams that are using these meters.

Economy drive

Corvette has been using the fuel flow meter in the second half of the season, and has been able to stretch its fuel to the limit to make up for what the team says is a disparity in on track performance with the other GT cars. The team says that it has not got a performance advantage on track through the Balance of Performance, or in the pits where its refilling time is longer than its competitors, but by being able to stretch the fuel to its limit it can deliver the results.

IMSA has confirmed that fuel flow meters will be mandated in 2018 for its prototype and its GT cars as it targets race capability rather than one-lap speed. 'Stint lengths [in 2017] continued to be a challenge for IMSA as the team fuel consumption reporting was questionable at best,' says Geoff Carter, senior director technical regulations and compliance, IMSA. 'For 2018, IMSA will require a spec fuel flow meter in the IMSA-mandated data-logger. The erroneous reporting led to incorrect refuelling restrictors/refuelling times and incorrect capacities.'