



23 March 2008 | 12.44:12 pm

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Article

February 2008

Keeping the pressure

Micro-electro-mechanical systems (MEMS) are attractive for a number of applications. Mike Cooke describes the use of MEMS and SAW devices for measuring tyre pressure in the automotive industry.

The automotive industry has used MEMS (Micro-electro-mechanical systems) for many years. Commercial success of this can be seen in an increasing number of examples.

One company in particular is using the technology to detect when and, perhaps more importantly, when not to inflate airbags.

More recent combinations of accelerometer and gyroscope MEMS have been developed to provide electronic stability control (ESC, and sometimes "electronic stability program" or ESP).

A further MEMS technology – pressure sensing – is now being used for tyre pressure monitoring systems (TPMS).

Unlike consumer electronics, new applications for car safety require extensive testing for robustness and reliability, putting the focus on years rather than months of development. US regulations often move safety technologies from being optional to standard.

Installation of airbags became compulsory in the USA, but most developed countries, including the UK, do not require them. However, they are often built in as standard even in mass-market vehicles outside the USA.

In the 1990s, numbers of SUV accidents in the USA – involving roll-overs and more than 100 deaths – were traced to tyre collapse. Millions of tyres were recalled by the manufacturer.

Low inflation pressures are a well-known contributor to tyre delamination and can also lead to reduced vehicle control, longer stopping distances, increased tyre wear and loss of grip, particularly in the wet.

The US government enacted the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act in 2000. TREAD includes the requirement that tyre monitoring systems be fitted to vehicles to catch dangerously low pressures. TPMS was phased in over the period of 2005-2007 in the USA.

That a level of compulsion is necessary was shown by a 2001 US National Highway Transport Safety Authority (NHSTA) survey of tyre pressures on the road.

Around 56% of cars had at least one tyre inflated to less than three-quarters of the recommended level.

In Europe and the Far East the emphasis for looking at such systems has been rather the improved fuel efficiency (and hence reduced CO2 emissions) resulting from driving with correctly inflated tyres.

Two main categories

Two main categories of TPMS – indirect and direct – have been developed. Indirect TPMS compares wheel rotation rates to gauge whether some, but not usually all of a vehicle's tyres are off-pressure.

Under-inflated tyres have a smaller circumference and have to rotate more to cover a certain distance. While such systems can be lower cost, they can fail to operate – for example, where all four tyres are under-inflated.

The TREAD act allowed in the initial phase-in the use of single tyre failure standards, but after November 2006 systems had to be able to detect if all

tyres were under-inflated. Some corrections to indirect systems can be derived from additional data such as vibration levels measured by inertial MEMS sensors in anti-locking braking (ABS) or ESC systems.

However, direct systems – where an actual pressure measurement is made – are more accurate and constitute the majority of systems designed to meet US government regulations.

It is in direct TPMS where MEMS pressure sensors have found application.

A number of structures are being used to provide pressure measurement for TPMS. One MEMS structure contains a vacuum cavity where the capacitance between the top and bottom of the chamber changes with pressure.

Another MEMS structure uses piezoresistive strain gauges in a diaphragm.

Surface acoustic wave (SAW) devices have also been developed for the application. A SAW-based resonator has a response that depends on temperature and pressure.

By combining a number of devices in different positions one can gauge both temperature and pressure. Temperature measurements are needed to correct for variation of the pressure sensor performance.

Since electronic connection with a rotating system is not ideal, most direct systems use wireless data channels between the wheel and the car electronic control system.

The measuring system is usually mounted on the valve assembly inside the tyre, although a number of newer systems are being mounted on the wheel rim. There are also proposals to incorporate TPMS into the structure of the tyres themselves.

Since there is no wire connection, the sensor unit needs to find an alternative source of power. Hence, the emphasis is on low-power consumption.

Integration

With increasing integration and small size/weight a requirement, some companies have developed systems-in-packages that contain almost all that is needed for the tyre-end of the monitoring system.

Along with separate MEMS variable capacitive pressure sensors, Freescale has a device (MPXY8300) that has xz-accelerometers, microcontroller, RF transmitter (315-434MHz) and a low-frequency input for receiving diagnostic commands.

The only extra components needed are the power source (3V battery) and aerials for the RF/LF communications. The accelerometers are designed to detect wheel speeds and directions of rotation.

Sampling rates in such systems usually depend on car speed. Infineon SensoNor's SP35 contains similar capabilities to Freescale's device although its acceleration sensing is radial rather than xz.

The SAW approach has been developed by UK-based Transense. This company is aiming at licensing its technology for others to produce.

Texas Instruments is providing some technical collaboration such as its TMS320F28x digital signal controller as a key component in the development effort.

Transense has also worked on this application with Michelin, Lear Corporation and TAI-SAW. Other companies such as Kyocera and Murata have designed SAW devices for TPMS use.

Power management is a vital part of the tyre-side of TPMS. Lithium thionyl chloride batteries are commonly used for low-current, long life applications.

However, the materials in these batteries constitute hazardous waste. Although TPMS units are designed to last seven years or more, early failure can occur and constitutes a significant replacement outlay.

Several ways to create battery-less tyre modules have been explored with some due to be introduced to the market in the next year or so. Wireless

power transmission from the vehicle side ranges from low-frequency magnetic induction to UHF (2.4GHz). One company promoting LF magnetic induction is ETV based in Australia. The company reports a number of commercialisation partners for its VisiTyre system and says that it is on track to implement the only battery-less TPMS on the market later this year.

German company IQMobil is promoting a UHF RF system that seems to work along the lines of passive RFID technology: the car side antenna transmits a signal to stimulate a quartz crystal whose vibration varies with temperature or as influenced by a capacitive pressure sensor.

More speculative is the hope that MEMS based "energy-scavenging" from vibrations can replace the use of battery power.



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