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Battery Monitoring for Hybrid Vehicles

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The market for hybrid gas/electric and diesel/electric vehicles is starting to gather pace, especially in the US and Asia. These vehicles bring new requirements for accurate monitoring of battery condition. For hybrid vehicles to operate at maximum efficiency, the full capacity of the battery must be used during every discharge cycle (when the car is running the electric motors and the combustion engine is not consuming energy). If the control system turns the combustion engine on before the battery is fully discharged, fuel consumption is increased. If, however, the restart of the combustion engine is delayed for too long, there is a risk that the battery will fully discharge, and the car will "break down."

In a conventional vehicle, it is only necessary to monitor relatively low charge and discharge currents to ensure that the battery is being maintained at an adequate state of charge. However, with hybrid vehicles, both low and high currents must be monitored. For the battery condition to be evaluated fully, the measurement system must measure both drain and charging currents and have excellent accuracy at both low and high currents.

Coulomb counting is a way of determining the state of charge of a battery by measuring the current entering and leaving the cells as a basis for calculating the remaining capacity. The charge transferred in or out of the cell is obtained by integrating the current drain over time. As with many electrical measurements, corrections are necessary for a number of sources of error across a typical cycle representing normal use of the battery.

In order to measure exactly the charge that has flowed in and out of the battery, it is necessary to evaluate what creates an error in each measurement. The four causes of error are electric offset, magnetic offset, gain error and linearity error. Some modern sensors incorporate an ASIC that corrects any linearity errors, so this factor does not need to be considered in the evaluation.

The error (expressed in Ah) of any measurement can therefore be expressed as:

$$\varepsilon = \left(\varepsilon_{elec\_offset} + \varepsilon_{mag\_offset} + \varepsilon_{gain\_error}\right) \times \frac{t}{3600}$$

The electric offset error remains constant across the measuring range. The gain error is directly proportional to the primary current.

The magnetic offset depends on the magnetization of the core, which in turn is determined by the current that has been previously flowing through the sensor. The material therefore exhibits a memory effect, with the error linked to the history of the cycle as well as the sensor. The hypothesis is that the error due to the magnetic offset is directly proportional to that offset. Although this has been confirmed by practical evaluation, it has not yet been proven by a theory.

Evaluation of a sensor's characteristics requires four current measurements: one at maximum positive current (IPA), then at zero current (IPB), then at maximum negative current (IPC) and finally a second measurement at zero current (IPD) (Fig 1). The sensor measurements for each of these currents are also recorded as IMA, IMB, IMC and IMD.

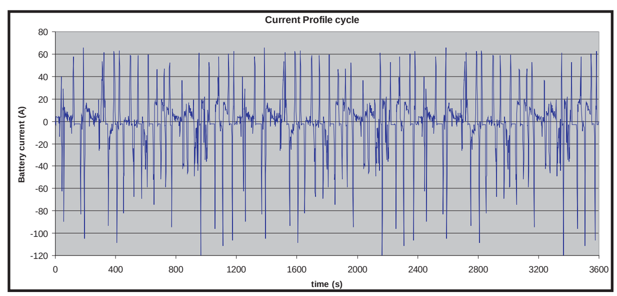

Figure 1. Standardized Current Profile

As mentioned earlier, there are separate magnetic circuits for the two measuring ranges, so it is necessary to evaluate the errors for each range separately. This therefore requires eight measurements, four for each of the two sensors.

The error during the calibration cycle would follow those shown in Figure 2. The measurements taken can be used to calculate the three sources of error.

The electrical offset (OFFSET) can be calculated as half the sum of the sensor measurements for the two zero current situations. This calculation cancels out the magnetic offsets, and there is no gain error as this is proportional to the current.

The magnetic offset (MAG) is half the difference of the sensor measurements with zero current. This calculation cancels out the electrical offsets, and there is no gain error as this

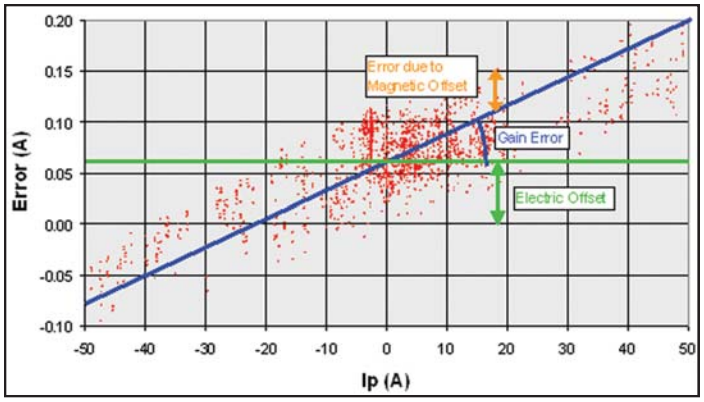

Figure 2. Transducer Output Error for Given Current Cycle

is proportional to the current.

The calculation of gain error is slightly more complex. The actual gain is represented by the difference between the two peak measurements, divided by the difference between the peak currents. The gain error is therefore this value, less the theoretical gain. These calculations are expressed mathematically below:

- $$OFFSET = \frac{I_{mB} + I_{mD}}{2}$$
- $$MAG = \frac{I_{mB} - I_{mD}}{2}$$
- $$\xi_{Gain} = \frac{I_{mA} - I_{mC}}{I_{pA} - I_{pC}} - Gain_{theoretical}$$

This technique is used to evaluate the current integration error for a high number of cycles. It is necessary to make an entire cycle measurement with a representative set of samples to determine the electric offset, the magnetic offset and the gain error. However, once these coefficients have been calculated, the current integration error for another sensor can be evaluated very quickly, because it is only necessary to apply the calibration cycle (which is short) to determine the sensor's characteristics, and then make a short calculation, which is almost instantaneous.

By using this technique, the accuracy of measuring the charge in a hybrid vehicle's battery is dramatically increased, allowing the control electronics to count the charge (coulombs) actually in the battery. This improved accuracy and enables automotive engineers to maximize efficiency without compromising vehicle reliability.

When using this technique, it is important that the sensors are optimized, not purely in terms of gain and offset, but in terms of coulometry (rate of charge/discharge). For example, LEM's DHAB family of Hall-effect sensors are optimized to measure the difference between currents in and out. To ensure that it can offer the required accuracy across the very wide range of currents experienced in a hybrid vehicle, each sensor can measure two separate current ranges, one between ±20 A and ±80 A and the other between ±50 A and ±600 A. This enables full-range current measurements to be made in combination with highly-accurate measurements at lower currents, with good resolution on both ranges.

Luc Colombel became the vice president of Traction and Automobile Industry for LEM in 2005, having served the company since 1996 as the Business Development Manager, Automotive. He holds an Engineering degree from ESIGELEC in Rouen, France and is a Member of the Society of Automotive Engineers. During his career, Luc has been responsible for a number of innovations, and holds patents concerning current, throttle sensors and magnetic applications.

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