The end of sensored BLDC control?

Thomas Freitag, Melexis, www.melexis.com

Vehicle manufacturers are increasingly appreciating the benefits of Brushless DC (BLDC) motor control as a response to the challenges of making their fleet meet legal fuel economy regulations. Brushless DC motor control typically increases efficiency 20 to 30 percent compared to equivalent speed controlled DC solutions. Furthermore they may offer a weight and size reduction of up to 50 percent especially in high temperature environments like in the power train. Electric and hybrid vehicles generate less noise especially at lower speeds, making low noise BLDC motors the preferred solutions for pumps and fans that have been taken off the belt.

Figure 1. Integrated electronics inside an electrical water pump.

Brushless motor control requires the accurate knowledge of the commutation points to achieve the praised (lauded) efficiency. A first method requires the application of Hall Effect based sensors in order to detect the rotor position. Next to the cost of the sensors, their implementation renders the motor and pump design larger and more complex. For fuel pumps, the implementation of commutation sensors incurs prohibitive sealing costs from the aggressive fuel environment and is therefore not considered. A second - sensorless - method detects the commutation points via the stator coils.

This technology does not suffer the above limitations and has been in production for some years in high end car models mainly for fuel and water pumps, engine cooling fans and HVAC blowers.

In these first generation sensorless solutions the commutation points were captured using BEMF sensing on a free running coil. For noise-sensitive applications like HVAC blowers, sine wave BLDC motor control, also referred to as Permanent Magnet Synchronous Motor (PMSM) control, is applied. For PMSM control there is no free running coil, but instead Field Orient Control (FOC) - also called Vector control - was applied using multiple shunt inputs in combination with DSPs, making component, development and validation cost such that sine wave motor control was only viable for high end models. Additionally FOC control had to be complemented by sensored operation for reliable start up and operation at low speeds.

Automotive electronic suppliers have developed, based on this first generation experience, a range of Application Specific Standard Product (ASSP) solutions and control algorithms to expand sensorless BLDC technology into a wider range of applications by reducing development complexity and component cost.

An example of a basic BLDC application is a speed controlled fuel pump that should replace a legacy DC solution. In these so called Mechanical Returnless Fuel delivery Systems (MRFS), the fuel pressure is mechanically regulated; the motors don’t see significant load changes; and the speed regulation is only to optimize for fuel economy and extend service life, not to respond in real time to a change in demand. Standard zero crossing BEMF detection in six–step, or so called block, mode is enough.

The only challenge is to start up in a reliable and fast way. Current solutions often still rely on rotor pre-positioning during start up. During rotor positioning, the BLDC motor is forced twice in stepper mode to a predefined motor state in order to ensure that the motor will start in the correct direction. Starting up is done in an open loop mode by applying the maximum allowed current to accelerate the motor as fast as possible to a speed where BEMF can be captured.

When no BEMF signal is available, today’s state of the art is to sense the rotor state by measuring its influence on the stator coil inductance values, so called reluctance sensing. The MLX81200 Melexis BLDC motor controller is able to perform reluctance sensing as part of its TruSense sensorless technology. For low inertia applications like fuel pumps, the controller has demonstrated the benefits of reluctance sensing by reducing start up times from approximately 200 ms to 50 ms. By applying reluctance sensing at start up and during acceleration, the start up time tolerances are also significantly reduced, making the application very robust.

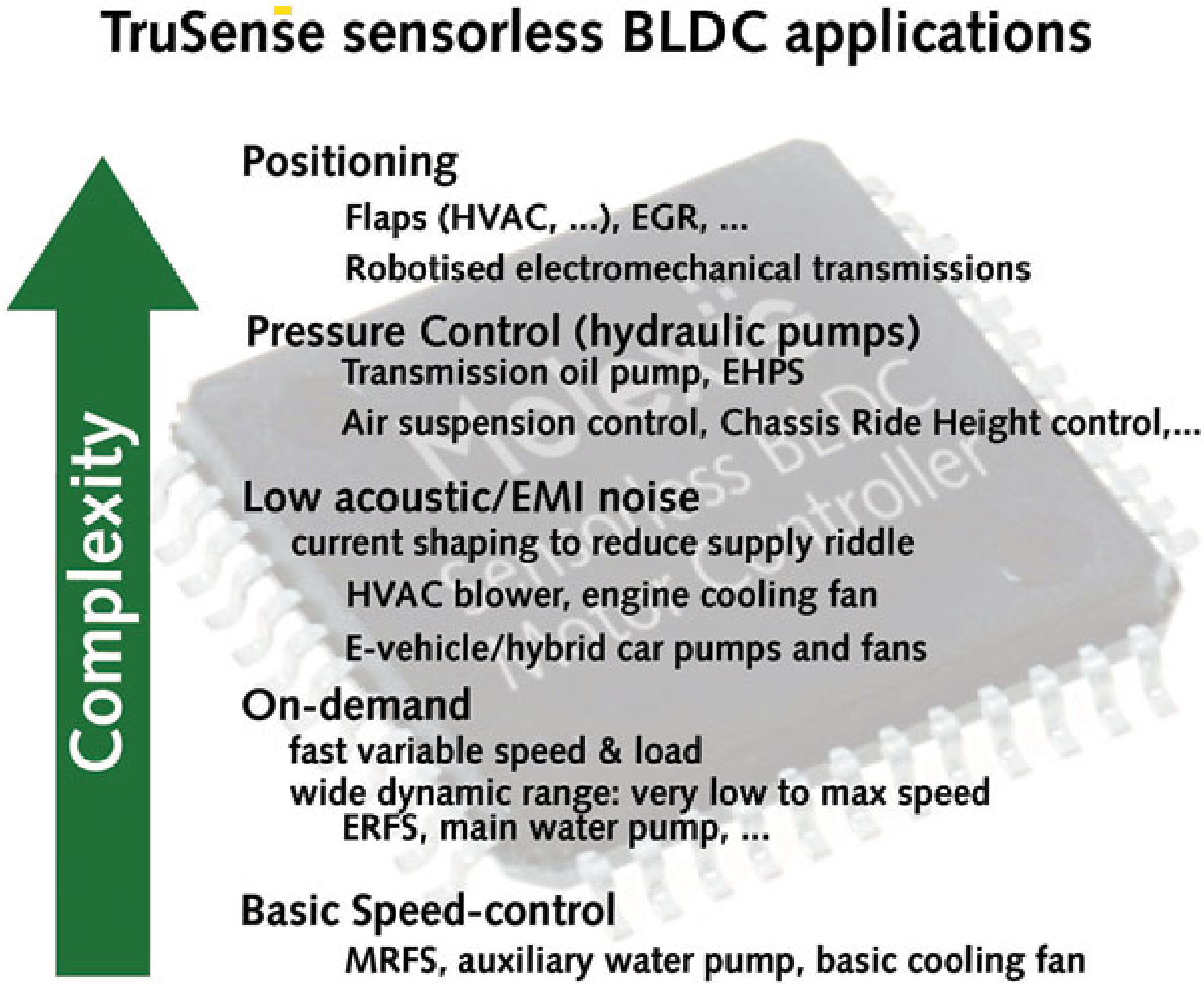

Figure 2. Sensorless BLDC application classification.

On demand: Fast speed and load changes
In MRFS, some headroom in flow rate has to be maintained. So-called Electronic Returnless Fuel delivery Systems (ERFS) do not apply a spill valve, and therefore offer a better fuel efficiency. The engine control unit (ECU) dictates the required flow rate to the fuel pump electronics based on feedback from a fuel line pressure sensor. In return, the fuel pumps in ERFS have to be designed with minimum inertia to vary flow rates with very fast response times. In a similar way, water pumps have to operate under sudden load changes due to air bubbles and ice.

When applying such fast acceleration/deceleration, or due to sudden pressure changes, the BEMF zero crossing may fall outside of measurable window. The MLX81200 measures the phase voltages, and extrapolates the position of the zero crossing from the voltage measurements. This ensures robust detection of the zero crossing, even when it falls outside of the measurement window (see Figure 3).

On demand: Wide dynamic range
On demand water pumps have proven to have one of the largest impacts on fuel

economy by reducing as much as 7g CO2/100km. Water pumps are required to operate at very low speeds to distribute the little available heat in an even way during engine cold start. On the other hand, this same water pump has to be able to deliver maximum flow rates under maximum towing conditions. In traditional engines with a belt-driven water pump, the aqua ducts had to be overdesigned to limit the water pressure at high motor revs. Therefore an engine designed to operate with an on-demand water pump can be made more compact and lighter.

To ensure robust operation at very low operating speeds, the MLX81200 integrates the BEMF voltage using Phase Integrators. At low speeds, voltage integration results in a net amplification of the BEMF signal while filtering any switching noise. Typically, the application of phase integrators allows a reduction of the minimum possible operating motor speed using classical control schemes by a factor of two to four.

Alternatively at maximum speeds, the zero crossing may be masked by the flyback pulse. Comparator-based technologies can only make best guess assumptions as to the exact position of the zero crossing, limiting the maximum torque, and leading to increased torque ripple while phase voltage measurements allow accurate extrapolation of the zero crossing. In exceptional conditions, for instance for a water pump operating under maximum towing load, efficiency is less of a concern. Then, phase integrators allow boosting of the motor speed by further increasing the lead angle at cost of the motor efficiency, disregarding any flyback pulse-masking effect.

Since the TruSense sensorless technology depend on the width of the BEMF measurement window to ensure robust zero crossing detection, the maximum motor speed can also be increased by applying overlapping motor states. Preferably the overlaps are realized as slopes - in so called trapezoidal control - to reduce torque ripple, acoustic noise and conducted emissions. The TruSense technology can also be applied in full sine wave, or PMSM motor control if noise is the critical design parameter (Figure 3).

As more and more electrical motors are applied to optimize fuel efficiency, they also increase the electrical load on the battery. To minimize this electrical load, any possibility to reduce the minimum operating speed is highly appreciated. The ratio between minimum and maximum speed (RPMmin/RPMmax) is referred to as the dynamic range. On a fuel pump application, the TruSense features of the MLX81200 reduced the dynamic range to approx. 5 percent (400 rpm/8000 rpm) compared to approx 22 percent of a standard DSP based solution (1800 rpm versus 8000 rpm).

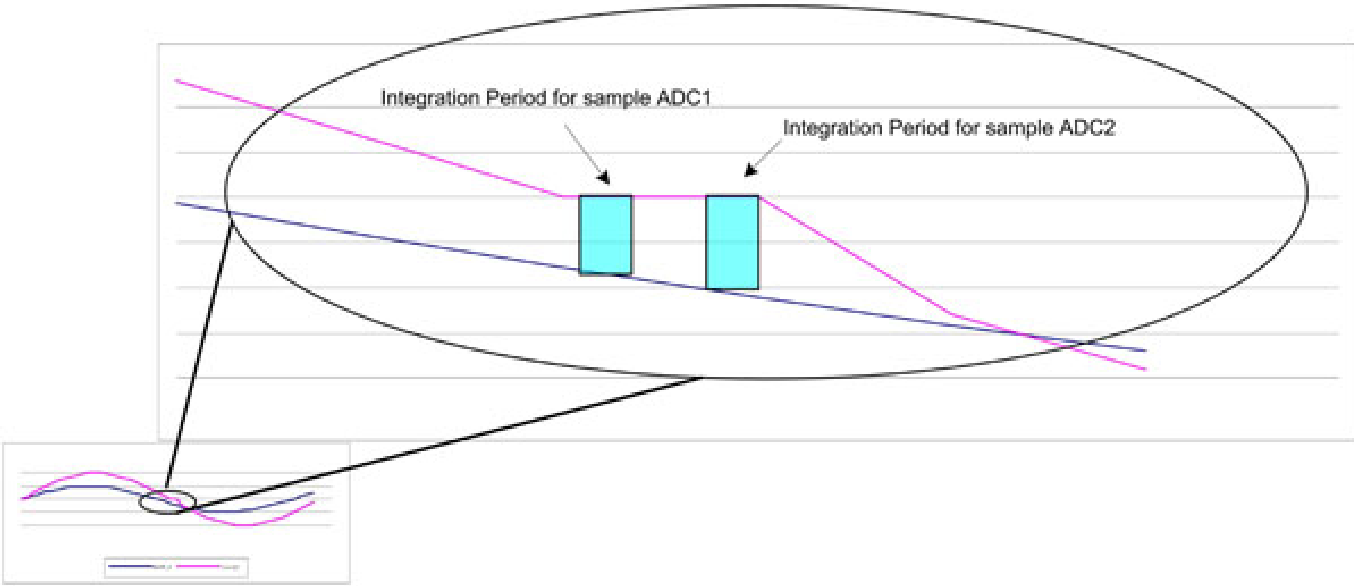

Figure 3. Phase integration guarantees tracking of the zero-crossing under severe load conditions with a narrow measurement window, enabling robust and high performing On-Demand operation. Blue line: BEMF Voltage, Pink line: Phase Current.

Pressure control
Hydraulic systems leverage the control capabilities of Brushless DC motors one step further by rendering an expensive pressure sensor obsolete. From motor speed and torque output information corrected for temperature effects and combined with specific pump information, it is possible to control the hydraulic pressure.

A key challenge to realize hydraulic pumps in a sensorless way is to ensure reliable and fast start-up under a wide range of loads. For instance, a 500-W transmission pump should start up to 12 Bar in less than 50 ms at -40oC with highly viscous fat as load, as well as at maximum engine temperature with liquid oil. The MLX81200 has shown that its TruSense sensorless technology is able to meet these requirements in a very robust and reliable way.

Positioning applications
Combining reluctance sensing at low speeds with BEMF sensing at higher speeds, today’s state of the art sensorless BLDC motor controllers like the MLX81200 are able to track the rotor position over the complete speed range and independent from the applied load, not only for pumps and fans -- positioning application sensorless technology might find its applications. The core idea is to use the sensorless rotor position detection algorithms and to calculate and regulate to a given position of the actuator because this is required for a flap and valve control or for car seat positioning.

Figure 4. Sensorless BLDC HVAC flap with LIN communication interface.

Feeding back the sensor information of the remote BLDC motors into the ECU requires up to 12 (!) wires in the wiring harness, and an equal amount of connector pins on the ECU PCB; each connector pin and sensor being a potential cause for reliability problems. Removing the commutation hall sensors and reducing the connector size not only reduces costs, but also reduces actuator size. By replacing the sensored predriver by an MLX81200, the application is optimized in cost, reliability and removes the motor control tasks from the ECU. Additionally, the MLX81200 is able to increase the maximum speed and reduce EMC by applying more intelligent motor control, like overlap, current shaping as discussed above.

Summary
The need for improved fuel economy is generating a large need for cost effective and reliable solutions to drive electric motors under very challenging conditions. With the smaller raw material cost and inherent higher reliability, brushless motors are the obvious way of the future. Today’s capabilities of sensorless control bring the future already a significant step closer. New developments in hard- and software will continue to increase performance and reduce cost.

More information can be found on www.melexis.com/mlx81200 [1]

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