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embedded systems
in automotive and military/aerospace applications

Latest Technology Opens Way for New Generation of Actuators.

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Cover: ON Semiconductor's family of motor-driver ICs is ushering in a new generation of stepper-motor-based actuators.

The automotive sector is showing signs of recovery and the military/aerospace continues to grow, so *EPN* is pleased to present this supplement looking at embedded-system application in these important markets. To inquire about any advertisements or products covered in this issue, you may use the reader inquiry card, or inquire online at www.epn-online.com.

embedded systems

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Proportional Control with Automo

By Bart de Cock and Steven de Preter, ON Semiconductor

Many automotive applications make use of valves to control various physical parameters. Sometimes these valves are operated only in two positions: open or closed. With changing market requirements—improved fuel consumption, reduced gas emissions, conformance to more stringent safety regulations, and enhanced comfort—a growing proportion of automotive valves are now requiring more precise control and a broader array of possible settings. Recent developments in motor-driver technology have resulted in a new generation of stepper-motor-based actuators.

In a number of automotive applications, stepper-motor actuators are already providing what one might consider a balanced solution for the specific task—with an optimised mix of features, cost-effectiveness and quality. These applications include small positioning functions such as headlamps, HVAC air-flaps, idle speed control and LPG expansion valves. For many proportional-valve applications, stepper motors are often labelled as being not suitable: open-loop position control is not possible as it requires an additional position sensor, and there is a risk for resonance taking place, resulting in noise, vibration and step-loss.

However, these assumptions no longer hold true as advanced stepper-motor-driver technologies can bring the solutions needed to resolve these issues. The addition of an external position sensor is, for most applications, not a reasonable option. Especially for stepper motors, there is a way to create a closed-loop positioning system if one looks at the motor itself as a sensor. Figure 1 shows diagrams related to a stepper motor that is suddenly accelerated and operated at a constant speed followed by a stall condition. The rotor position is increasing in a linear way, followed by a constant (stalled) position after a certain point. The speed oscillations—due to sudden acceleration—are visible in the rotor-speed diagram and reflected in the sampled Bemf waveform. The stall condition is visible in the Bemf signal when rotor speed suddenly falls to about 0rad/s. Looking at these diagrams, one can say that a stepper motor contains, by its own construction, an "embedded virtual sensor" and that its output signal is accessible simply by means of Bemf sampling, resulting in a reliable sensorless stall-detection method. An analogue output pin called SLA (speed and load angle) on the motor driver allows direct access to the Bemf samples.

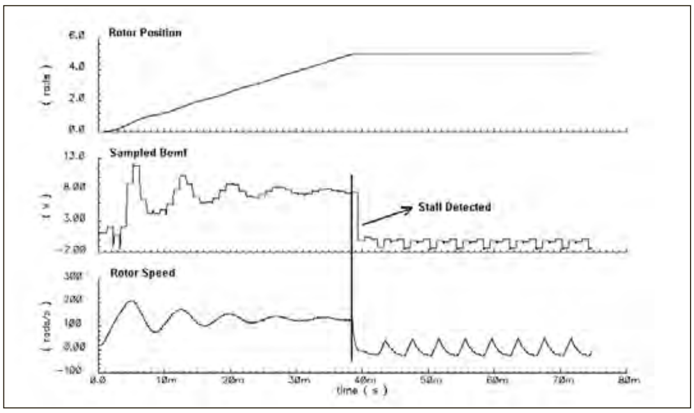

Figure 1: Using the motor as a sensor.

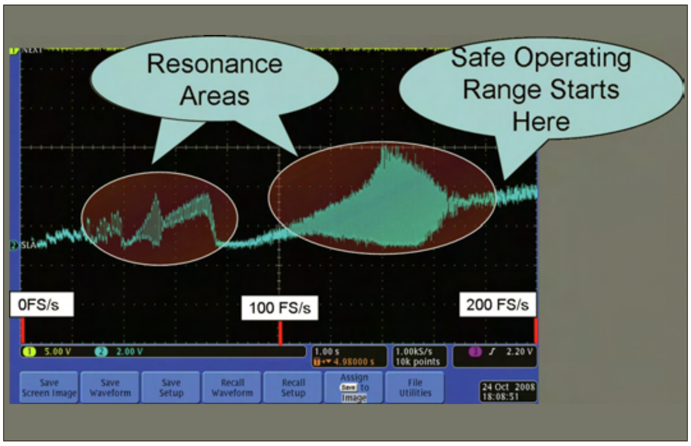

Figure 2: Resonance characterisation.

Characterising areas of resonance

The embedded virtual sensor, accessed through the SLA pin is useful not only for stall detection, but also for trouble-shooting resonance issues. When verifying resonance characteristics in a stepper-motor application, the first difficulty has always been to find a suitable sensor and means to attach it to the system. In most cases, this task had been close to impossible as typical stepper-motor applications did not have an embedded sensor, nor did they have enough available space to accommodate one. Furthermore, when mounting the sensor, it was imperative not change the mass or friction on the motor axis as this would have altered the resonance behaviour to be measured.

Today these issues can be resolved, because the rotor movement can be observed through the embedded virtual sensor. Figure 2 shows the outcome of a resonance-characterisation session that was accomplished—by means of a pulse generator—to sweep the stepper-driver frequency and an oscilloscope connected to the SLA pin of the stepper-motor driver. The characterisation runs did not require the mounting of any sensor hardware, since the stepper motor driver itself captured and output the Bemf signal.

Air-conditioning flap control

Air-conditioning flap-control actuators can also benefit from a stepper motor's sensor capabilities. A stepper-motor driver with embedded stall detection enables the system to detect very accurately the end stop of a flap in an HVAC air-distribution channel. Typically, this end stop is reached on purpose during a movement, for example when the flap is operated in a near-closed position. But the end stop can also be hit due to erroneous operation or because of small mechanical tolerances. Normally, more than thousand full steps are required to bring a flap from a fully opened to fully closed position. Because of the gear-construction inside the actuator and the thermal expansion of the air-ducts and mechanical tolerances around the flap, the full stroke of an actuator can change over tens of full steps. It is important to realise that the amount of air that flows through a nearly closed flap is a non-linear function of the flap position. As a result, for a flap that controls small amounts of airflow, this results in a relatively large error on the airflow. This error is introduced by the mechanical tolerances of the duct/actuator system. So to control accurately and fully proportionally the amount of air flowing through an HVAC duct, an adaptive and closed loop algorithm needs to

tive Stepper-Motor Valves

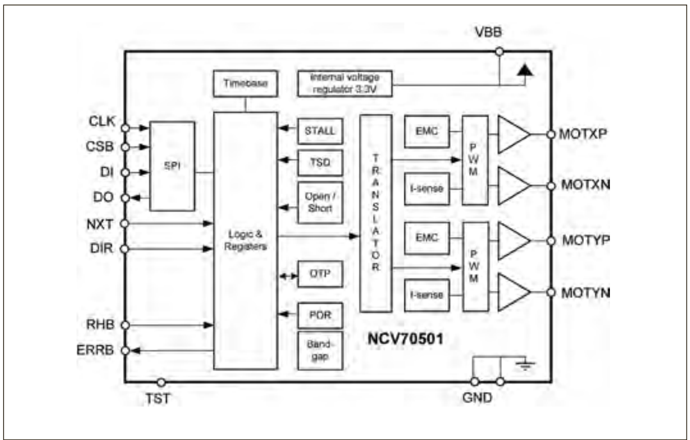

Figure 3: A block diagram of the NCV70501 motor driver.

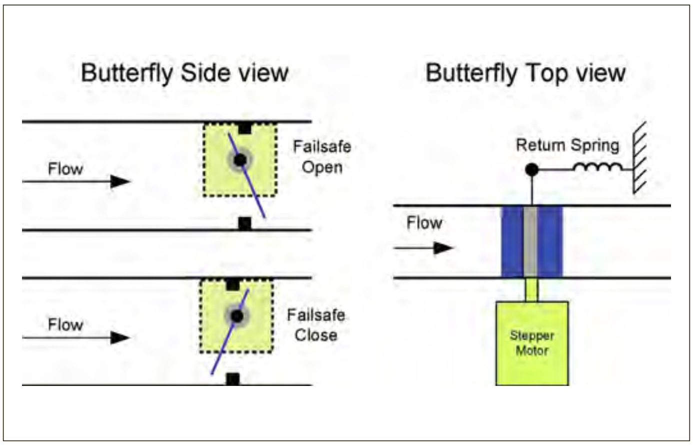

Figure 4: A failsafe proportional valve.

be employed. Adaptation will remove the influence of mechanical variations and tolerances on the airflow. The closed-loop aspect—or merely pseudo closed loop—consists of running deliberately into stalled condition once in a while. The stall detection then allows accurate marking of the new positions starting from the fully closed flap position. By doing this, even the smallest flap openings can be maintained accurately and reached repeatedly, yielding true proportional control. A device that can enable the detection of the end stop within one full step will avoid noise and vibration arising during the stall condition. Single full-step detection also allows the rotor and stator-magnetic fields to remain synchronised. This avoids any risk of demagnetisation of the rotor due to AC magnetic fields from the stator, and it will help maintain a stable actuator torque over lifetime.

The NCV70501 (Figure 3) motor-driver IC has a push-pull drive configuration, which makes it fully compatible with the new generation of automotive bipolar stepper-motor actuators. Bipolar motors were developed years ago and have been brought successfully into automotive production. Until recently, these motors were embedded only in LIN mechatronic HVAC actuators. Today, for HVAC systems equipped with only a few actuators, LIN mechatronic actuators do not offer any cost benefit. Therefore, the motor drivers are typically placed inside the HVAC control head and not inside the actuators. Based on the bipolar stepper motors, the IC has been developed specifically to enable direct drive architectures of this sort.

Bipolar motors inherently save—when compared to the more frequently used unipolar motors—on wiring, size and weight. Only four wires are needed to drive a bipolar motor, as opposed to five wires for a unipolar motor. Bipolars require only half the mass and volume of the cupper windings of their unipolar counterparts to produce the same torque. It also is to be noted that certain desirable functions, such as efficient micro-stepping or stall detection, are hard to develop for unipolar stepper-motor actuators.

The IC, in combination with a bipolar stepper motor, can also compete with brush DC motors. In general, stepper motors have a clear quality advantage over brush DC motors, because they operate contact-less while brush DC motors suffer from noise and wear to the brush contacts. Brush DC actuators also typically require the installation of additional sensors or pulse-count interface circuitry, with related wiring and/or costs. Although the cost of the motor driver for a brush DC motor is typically lower than that of a stepper-motor driver, looking at the total picture, stepper-motor-based actuators tend to offer better features for the same total system cost.

There is also a challenge from the IC to one of the main advantages of brush-DC-motor actuators, notably the ability to rotate as quickly as the supply voltage and load allows. Speed-critical positioning is now made possible for stepper motors by means of a dedicated adaptive-speed motor-drive algorithm. The algorithm allows speeds up to 1000 full steps per second. The motor is operated at the fastest speed possible, adapting speed automatically to the actuator and flap characteristics—that is, the load. During this adaptive-speed operation, sensorless stall detection is active, guaranteeing error-free positioning. This algorithm has obviously benefits in situations where a recirculation flap needs to be closed as fast as possible.

Proportional engine-control valve

Another potential area of interest is valves that are directly connected—that is, without gearbox—to the stepper motor. Such as valve can, for example, control gaseous or liquid flows. It is estimated that through available automotive stepper motors, holding torques of up to 0.2Nm can be achieved with coil-currents of ~1A. Figure 4 shows a possible configuration of such a valve.

When a failsafe condition is needed, either failsafe-open or failsafe-closed can be chosen. If required, an additional return spring can also be added to ensure proper closing of the valve—for example, when no current is supplied to the motor. An important aspect for the application of this kind of valves is the required rotational resolution. Typical automotive stepper motors have only 24 electrical full steps over an entire mechanical rotation, yielding a rotation angle of 15° per full step. This is a fairly limited mechanical resolution for a butterfly valve, but it can be improved by adding a gearbox or by means of microstepping. The NCV70521 allows 1/32 microsteps per full step. One of the big advantages of the motor-driver IC for the HVAC application is that its SLA output also enables step-loss detection during low-speed operation, eliminating position sensors and related interface electronics. Also, the current level of the IC can be set quite flexible, allowing easy adjustment of the required torque to move the valve. Finally, thanks to the IC's 100% diagnostics capability, the creation of a new kind of high-quality, yet low-cost, valves is possible.

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