Motor and Resolver Integrated

The Mosolver is an innovative closed-loop motion actuator which infuses a position feedback sensor into the magnetic structure of a high pole count AC hybrid servo motor. The position sensor coils are placed within the motor structure so as to intercept a portion of the flux used to operate the motor. The ripple current associated with the PWM drive provides the flux variation required to induce a voltage in the sense coils. When properly sampled, the sensor output provides sine and cosine information similar to a resolver, and these signals are available even when the motor is stationary. **Donald P. Labriola, QuickSilver Controls Inc., USA, Edward Hopper, Maccon GmbH, Munich, Germany**

High pole count Permanent Magnet AC synchronous motors, when operated in open loop, are called microstepper motors. The high pole count design produces superior torque density, while the highly tooled production combined with the low quantity of rare-earth magnets required result in a low cost motor. Open loop operation also typically uses very simple control schemes. Unfortunately, when operated in open loop, these motors are subject to low and mid frequency resonances, lost steps, and drop-out. They typically are used at one-third to one-half of their torque rating, wasting significant torque capability while also producing excess heat.

These same motors, when operated in a true closed loop mode, such as Vector control, are known as Hybrid Servos. Closed loop operation eliminates the low frequency resonance associated with the rotor inertia interacting with the rotary magnetic “spring” constant. Commutating the motor causes the stator field angle to track the rotor position so as to produce the maximum torque for a given commanded current.

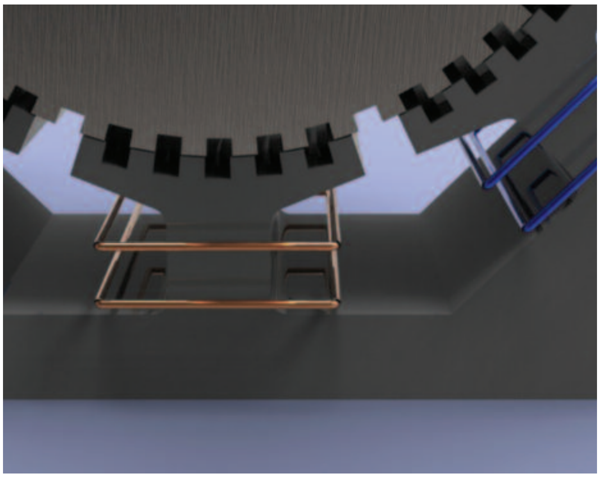

Figure 1: Sense coils and rotor-stator alignment

Mosolver construction

Microstepper class motors are typically constructed with the tooth spacing on the stator slightly different from that used by the rotor to prevent all the teeth from aligning simultaneously. The simultaneous alignment gives rise to large detent torque as well as cogging. Figure 1 shows a typical 52:50 tooth spacing. The teeth on stator are set at a slightly tighter angular spacing (as if there were 52 teeth) than those on the rotor (with 50 teeth).

Figure 2 (left) shows the sense coil used in the 2-phase Mosolver tested. For this stator design, using sensing coils on all eight stator pole structures helps cancel out the effects of rotor runout and minimizes the number of turns required for each sensor coil to get robust signals. Each sensor coil is split into four quadrants with quadrants 1 and 3 being wound in the clockwise direction while quadrants 2 and 4 are wound in the counter clockwise direction. The voltage produced by a particular quadrant of the sense coil is dependent upon the number of turns of that coil, and the rate of change of the flux

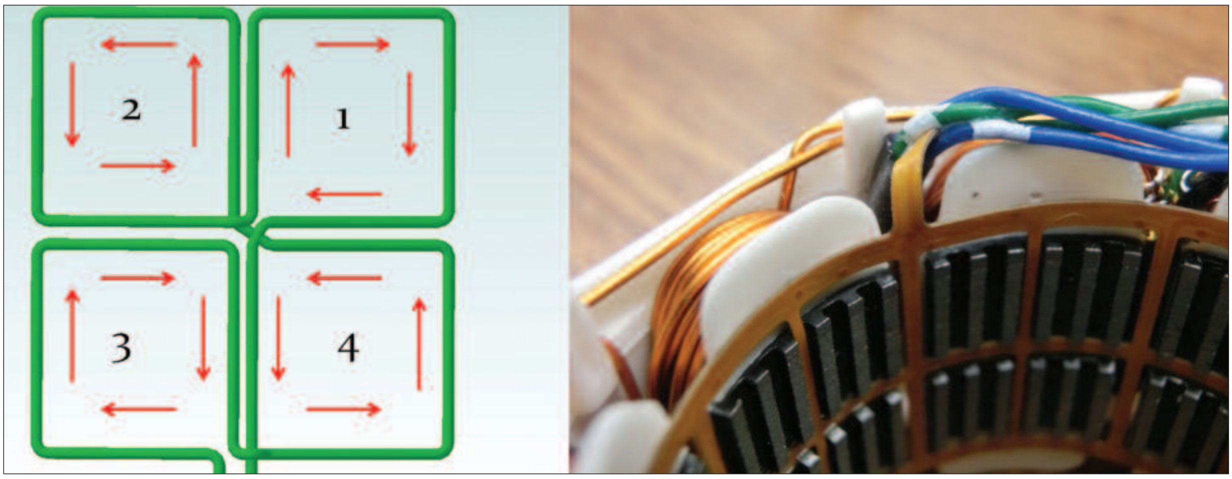

Figure 2: Sense coil implemented as a flex circuit used in the 2-phase Mosolver

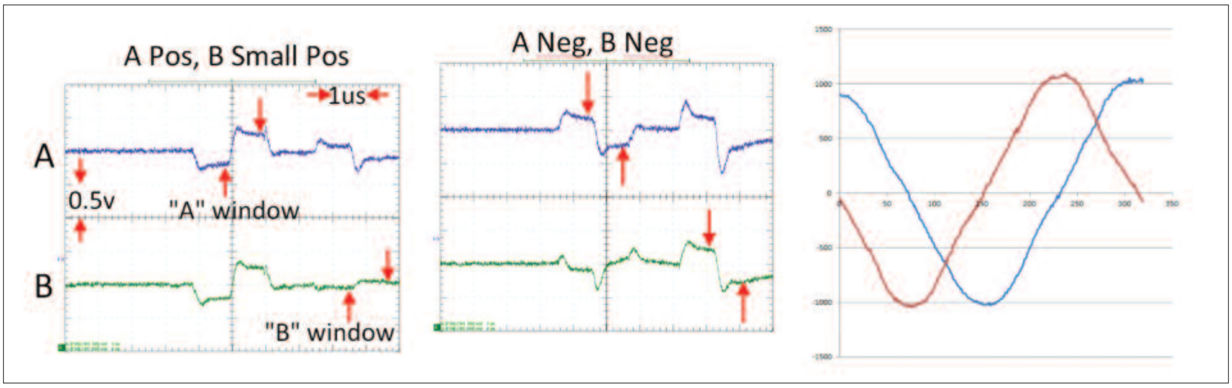

Figure 3: **Analog signals from the sensor coil signals after they have been multiplied by 3 by a differential amplifier (left, middle), and sampled data from the Sine and Cosine windings taken while the Mosolver is rotating**

passing through that coil window, while the polarity is affected by both the sign of the rate of change of the flux and by the direction in which the coil is wound.

The total voltage produced by the sense coil depends on the division of the stator flux (and thus ripple) into different groups of teeth passing through the various sense coil loops, the division being moderated by the relative overlap of the stator teeth to the rotor teeth. With the sense coils in sectors 1 and 3 wound in the opposite direction compared to sectors 2 and 4, the output signal resulting is related to the difference in the rate of change of flux through sectors 1 and 3 versus that through 2 and 4.

Physically, the sense coils were implemented as a flex circuit which is inserted into the stator before the rotor is inserted. The sensor is completely contained in the otherwise unused spaces within the stator structure and thus protected mechanically. The total weight of the system increases only minimally, and may actually be reduced due to the material removed to produce the groove in which the coil lays. As no material is added to the rotor, its inertia is not changed.

Sensor data

Figure 3, left and middle frames, shows the analog signals from the sensor coil signals after they have been multiplied by 3 by a differential amplifier. These signals are then sampled by the internal A/D converter. The sampling times are configured to take data at the end of the reverse pulse (just before the driver transitions to the forward pulse), and again about the same time into the forward pulse. This is done for both channels. The PWM logic must prevent multiple driver transitions while in the read window while still providing the PWM signals needed to produce the commanded torque for the system.

Figure 3 right shows the sampled data from the Sine and Cosine windings taken while the Mosolver is rotating. These signals are decoded into angle by the DSP (processor). The absolute angle within an electrical cycle provides sinusoidal commutation information for the motor, and does not require phasing adjustments as the same magnetic structure for the motor is used for the sensor. This electrical cycle repeats 50 times per mechanical revolution of the rotor within the stator. The processor extends the counts from each electrical cycle to track position over multiple revolutions of the motor. Each electrical cycle is divided into 640 increments producing 32000 increments per revolution. One electrical cycle (7.2 degrees mechanical) is shown. The Y axis is ADC counts, the X axis is time.

Conclusions

The shared use of the magnetic structure of a motor for both torque production and for position measurement has been shown effective and viable from stationary operation up to 4000 RPM. The resulting structure is compact and physically robust with the sensor completely enveloped within the motor structure. The signals are robust and the position sensing shows good resolution. The sensor is inexpensive, and there is very little impact on the electronics complexity for the digital drive. Phasing alignment of the sensor for commutation is not needed as the motor and sensor share the same magnetic structure.

This patented method has now been demonstrated in high pole count motors, and is also applicable to many other motor styles by appropriate placement of the sensor coils. The availability of inexpensive, compact, and robust position feedback in high pole count motors invites a transition to the improved performance of closed loop operation in a market segment currently dominated by open loop operation. The high torque density provided also allows these Hybrid Servos to also push up into the existing servos market segment through reduced size and cost, and the frequent elimination of gearheads.

Literature

Donald P. Labriola "Mosolver™ - Integrated Motor and Resolver – Operational", PCIM Europe 2014 Proceedings, pp. 227-232