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A Practical Primer On Motor Drives (Part 16): Torque, Speed, Position, And Direction Sensing

by Ken Johnson, Teledyne LeCroy, Chestnut Ridge, N.Y.

This last section of this motor drives article series returns to the topic of motor operation with an introduction to motor-related sensing. Depending on the application and the required complexity of control, a motor may be instrumented with or without sensors for detection of rotor speed and position, and the control system may be a closed-loop or open-loop design, depending on the application. In most cases, optimal operation of the motor by the variable-frequency drive requires some direct sensing of the motor operation (sensored) or control system calculation of these quantities from other known data (sensorless).

A motor running in a sensorless mode in normal operation would likely still be instrumented during design testing, or instrumented differently (e.g., one may use a quadrature encoder interface in an engineering debug and validation test, whereas the shippable product may use a resolver.) This part 16 discusses the different parameters that are measured in motor applications—namely torque, speed, and rotor shaft position—and describes operation of the various types of analog and digital sensors used to measure these variables. This section also demonstrates various measurements of sensor outputs that can be performed using an instrument such as Teledyne LeCroy's Motor Drive Analyzer.

Measurement And Sensor Types

Torque (usually specified as the symbol tau, or T) feedback sensors are nearly always analog devices with an analog output signal from a torque load cell corresponding to a specified torque value. The typical update rate of the output signal is very low as the load cell likely has on-board processing to convert sensed values into a torque reading (a "static" load cell.) Therefore, it is hard to sense torque and report torque values under rapidly changing conditions. So, most torque sensors are used in a final validation lab during static (steady-state) tests and are not included as part of a final motor or drive product. More advanced control systems derive torque from other known data, as necessary for feedback. Torque is expressed in a variety of different units, such as Newton-meters (N·m) or pound-feet (lb·ft).

Speed (usually specified as the symbol ω) sensors may output analog, digital, or encoded serial data signals. Depending on the type, analog and digital speed sensors can collect speed only, speed and rotational direction, or speed, rotational direction and absolute rotor shaft position information.

Absolute rotor shaft position is indicative of the rotor magnetic flux location, and knowledge of the latter is required in implementation of more complex motor control algorithms (e.g., vector FOCs.) Speed, position, and direction sensors provide instantaneous information at the sensor output and are highly suitable for dynamic measurements. Speed is expressed in either radians/second (rad/s) or revolutions per minute (RPM). Note that there is no industry convention for what rotor direction of travel (clockwise or counter-clockwise as the motor is viewed looking down the shaft) indicates positive speed.

An angle tracking observer is commonly employed to filter the speed calculation and provide a better estimation of speed with better resolution than would otherwise be available. The block diagram in Fig. 1 depicts the types of torque, speed, position, and direction sensors that one might attach to a motor.

Mechanical power at the output of the motor shaft is simply calculated as torque x speed. Thus, if we input torque and speed signals from a sensor to the Teledyne LeCroy Motor Drive Analyzer (or calculate them from other known inputs), then we may also measure motor output power, in kilowatts (kW) or horsepower (hp).

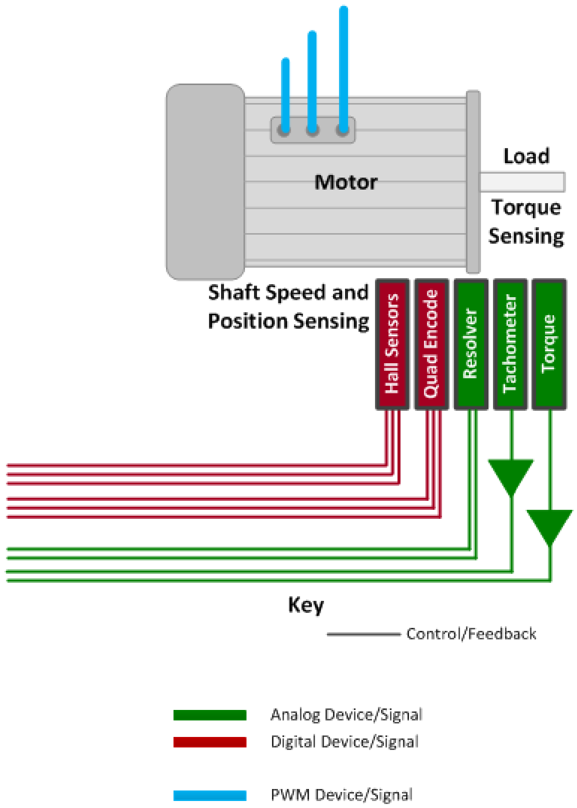

Fig. 1. Motors use a variety of sensor types to measure torque, speed, position, and rotational direction of the motor shaft.

Torque Sensors (Load Cells, Transducers)

Torque sensors convert a torsional mechanical input (like that present on a motor shaft) into an electrical output signal. They most commonly provide an analog output signal corresponding to a measured torque value. There are two basic types of analog output methodologies: 0-xVdc and mV/V. Additionally, analog output may be as a frequency-modulated signal, or could be embedded in digital serial data.

In all types, conditioning electronics are used to condition the sensed torque signal into an analog output signal to achieve higher accuracy and linearity. This means that the update rate of the torque sensor output may be less than the motor's rotational speed.

By definition, measurement of motor shaft torque requires a rotary torque sensor, which can fit over the motor shaft and transmit the signal to an output while the shaft is rotating.

0-xVdc Output

The 0-xVdc torque sensors output a linear, fixed dc voltage for a given torque input. An example would be 0 to 10 Vdc = 0 to 10 N·m (Newton-meters). Because their analog output signal is rather high, 0-xVdc torque sensors match up well with a Motor Drive Analyzer input channel.

mV/V Output

The output of a mV/V torque sensor is proportional to an applied dc power supply voltage. An example would be 10 mV/V for a 10-N·m torque sensor. Applying a 5-Vdc voltage to the torque sensor would result in a full-scale output of 0 to 50 mV = 0 to 10 N·m.

Because the analog output signal of a mV/V torque sensor is typically small (in this case 50 mV or less, full scale), the accuracy of the torque measurement through a Motor Drive Analyzer channel will likely not be as high as obtainable with 0-xVdc output torque sensors. An input of 50 mV full scale = ~7 to 8 mV/div on the input channel, which means that the Motor Drive Analyzer introduces more noise on the signal.

Analog Frequency

Some torque load cells provide a frequency-modulated output signal that is proportional to a torque value, with the output frequency at torque equal to zero being the mid-span of the modulation range. This type of torque load cell is more immune from analog noise and interference.

Other Torque Sensors And Sensing Methods

To reduce sensor costs, incorporate measured torque data into some other existing signal, or to permit the control system to calculate torque from other measured data, the following are often implemented in motor drive designs:

- Torque data can be embedded in digital form in a variety of different serial data signals for delivery to the control system. The control system then decodes the serial data information to extract the torque data.
- Torque can be inferred from either a simple torque constant proportional to current consumed by the motor (e.g., Torque = x N·m/A) or by use of a dq0 transformation I_q value (assuming the control system is performing this transformation.)

Analog Speed, Direction, Position Sensing

Analog Tachometer Signal

The simplest approach to measuring analog speed is an analog tachometer signal, with a tachometer output signal (0-xVdc) corresponding to some angular speed. In this case, there is no information regarding rotor shaft position, but signing the output voltage as either positive or negative indicates rotation direction.

Resolver

A resolver outputs two analog sinewave signals 90° apart (sine and cosine signals) to convey information on mechanical rotation and direction. It is essentially a rotary transformer with one primary winding and two secondary windings that are rotated 90 mechanical degrees with respect to each other as shown in Fig. 2.

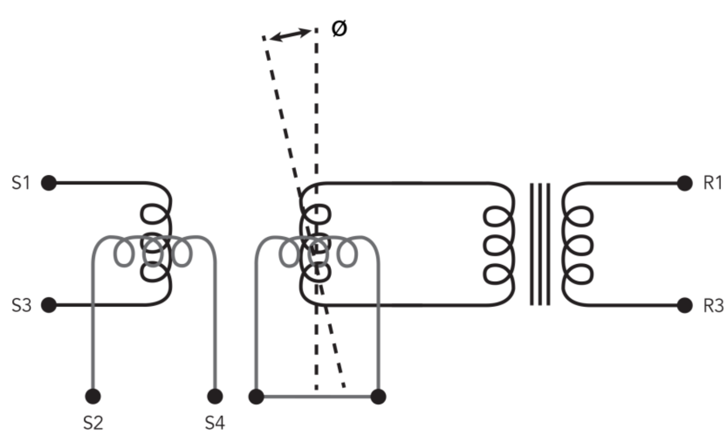

Fig. 2. A resolver generates two sine wave signals that are 90° apart. These signals can be used to determine shaft speed and angle.

A basic resolver has two poles (one pole-pair) and is known as a single-pole resolver. The excitation signal is input across R1 and R2 (in the figure above), and the output signals are sensed across S1 and S3, and S2 and S4. These output signals appear as shown in Fig. 3 for a single-pole (one pole-pair) resolver.

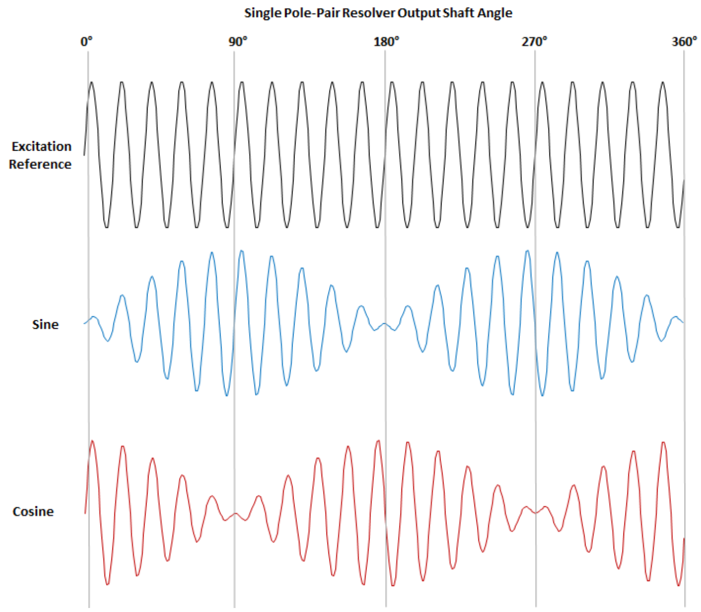

Fig. 3. A basic resolver with a single pole pair generates sine and co-sine outputs. One complete transition of the sine and co-sine waves represents a single rotation of the shaft. The rotor shaft angle (position) is calculated from the arctangent of the ratio of sine and cosine amplitudes.

For a basic resolver with one pole-pair, one complex sine/cosine pair equals one revolution, and the arctangent of the ratio of the amplitude of the sine and cosine signals determines the angle. We can attain more accuracy at lower rotational speeds by providing more than a single pole-pair in the resolver. By defining the offset angle from the resolver placement to the rotor magnetic field, we can calculate electrical rotor magnetic field angle, and then use this information to create measurements and waveforms of the rotor magnetic flux angle.

The example in Fig. 4 shows a resolver capture using the Motor Drive Analyzer. In this example, 2 s of time is captured. The excitation reference appears as C7 (red, bottom left grid) and the sine and cosine signals appear respectively as C3 (blue, top left grid) and C4 (green, middle left grid). The full acquisitions appear on the left, and the zooms of the full acquisitions appear on the right.

Both speed and angle values can be calculated and displayed as waveforms, and this is shown in Fig. 5 for the full acquisition. Note that the angle tracking observer (a type of filter that will be explained in a later section) is applied in this case to reduce the speed measurement variation to approximately ±5 RPM in a nominally 1000-RPM steady-state measurement.

Fig. 4. Measurement of resolver signals using the Motor Drive Analyzer. On the left side of the display, we see full 2-s acquisitions of the excitation reference (C7, bottom left), the sine output (C3, top left) and cosine output (C4, middle left). Zooms of the full acquisitions appear on the right.

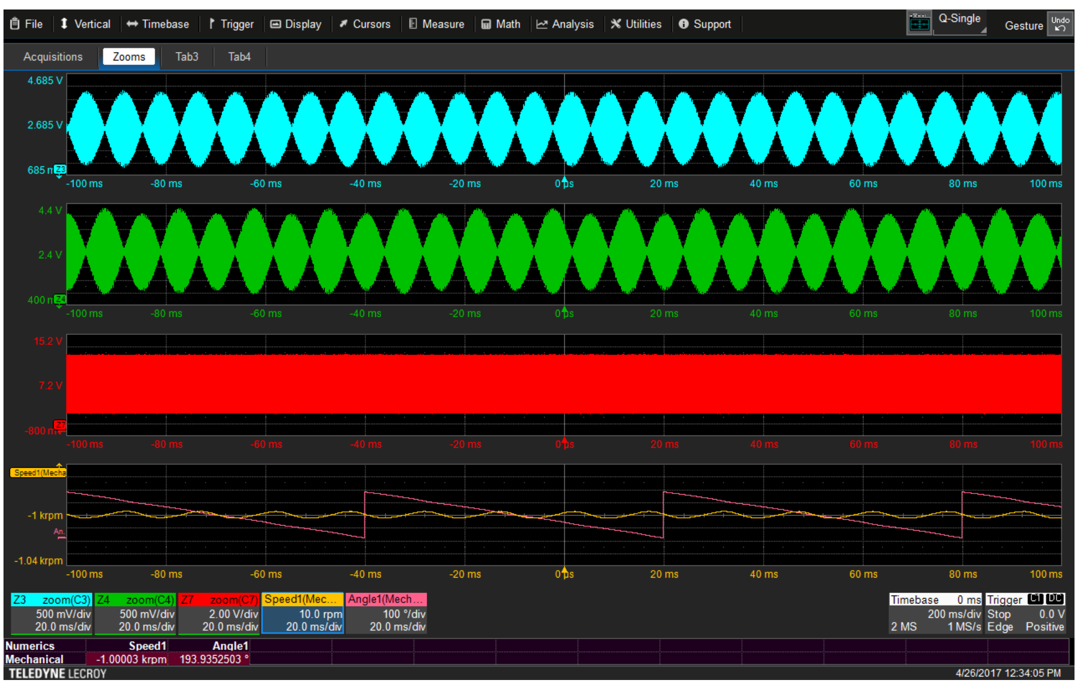

Fig. 5. The MDA calculates speed and angle values from the captured resolver waveforms.

Zooming in on the Numerics table in Fig. 5, we can more clearly see the mean values of speed and angle (Fig. 6.)

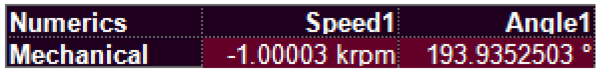

Fig. 6. A closeup of the Numerics table from the previous figure shows the mean values of speed and angle for the captured resolver waveforms.

The detail in Fig. 7 shows the setup for converting the resolver acquisition data to a speed and angle value, including the use of the angle tracking observer filter.

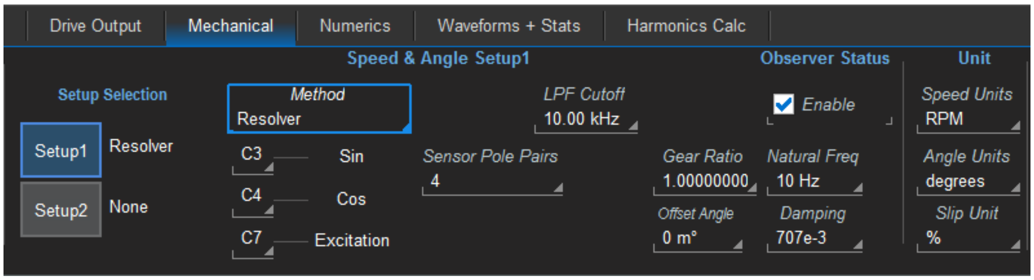

Fig. 7. The MDA is configured for converting resolver data to speed and angle values with the angle tracking observer filter enabled.

The example in Fig. 8 is similar, but it displays a 2-s capture of resolver signals measuring the dynamic movement of a servo motor shaft. From these signals, calculations (using the angle tracking observer) of speed and angle are made and displayed as waveforms. The resolver sine (M1, or yellow), cosine (M2, or magenta), and excitation frequency (M3, or light blue) along with speed and angle mean values and waveforms are shown in Fig. 8.

Fig. 8. Capture of resolver signals measuring the dynamic movement of a servo motor shaft. Resolver sine (M1, yellow), cosine (M2, magenta), and excitation frequency (M3, or light blue) are shown along with speed and angle mean values and waveforms.

Digital Speed, Direction, Position Sensing

Pulse (Digital) Tachometer Signal

A pulse (digital) tachometer outputs a TTL-level digital pulse that repeats N times per revolution, with N a known quantity. It provides speed data but not information on direction or position.

Hall Sensors

Brushless dc (BLDC) motors using six-step commutation most often use Hall effect sensors embedded in and around the rotor to provide a non-contact signal output representing rotor position. A Hall effect sensor actually has two components—a magnet and the actual sensor, which may also be referred to as a pickup.

In BLDC motors, the Hall magnets are typically embedded in the rotor, while the Hall sensors are mounted within an assembly that surrounds the rotor. In some cases, sensors may be mounted in the stator, though in practice, this approach is often avoided because of requirements for manufacturability.

These sensors are used to sense rotor position and then directly control the electrical commutation of voltage in the stator. The Hall sensor signals can be used to indicate rotor speed, from which shaft speed can be calculated.

Fig. 9 shows a cutaway transverse view of a BLDC motor with Hall-effect sensors.

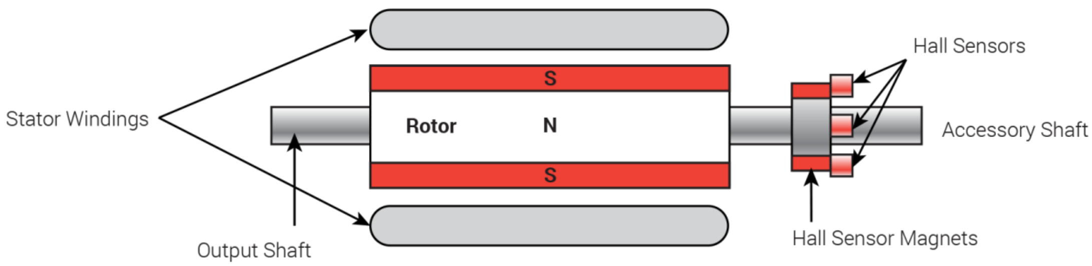

Fig. 9. Magnetic fields produced by Hall sensor magnets embedded in the rotor are sensed by Hall sensors mounted to an assemby surrounding the rotor. The electrical signals produced by the Hall sensors permit the control system to determine rotor location and speed.

The three Hall sensors provide pulse outputs that, when taken as a 3-bit binary string, provide six different values (values 000 and 111 being disallowed as they are not possible due to the mechanical configuration) that repeat in a defined order. One repetition of the six values corresponds to one rotation of the rotor for a motor with one rotor-pole pair, or two repetitions corresponds to one rotation of the rotor for a two-pole-pair rotor.

The sequence of the repetition indicates either clockwise (+RPM) or counter-clockwise (-RPM) rotation. Fig. 10 shows Hall-effect sensor signals for a three Hall-effect sensor configuration with the sensors placed 120° apart on the stator (equally spaced) and one rotor-pole pair. At every 120°, one of the Hall-effect sensors makes a positive transition (the figure shows 60°/horizontal division) and one electrical cycle is completed in the same time as one mechanical shaft revolution.

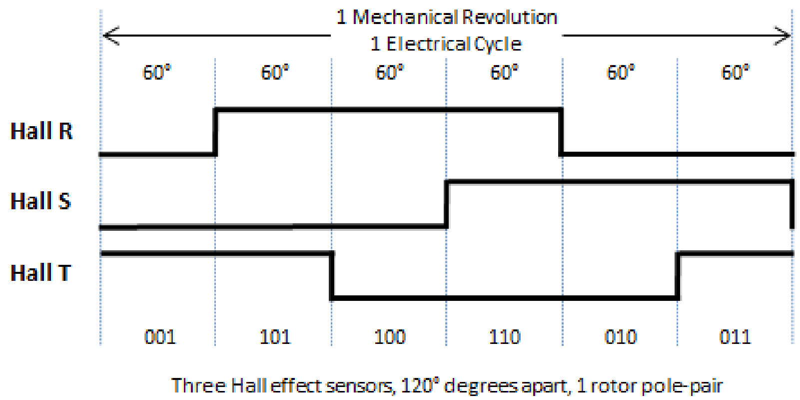

Fig. 10. In the BLDC motor of Fig. 9, one of the Hall-effect sensors makes a positive transition every 120°. In the case of a motor with a single rotor-pole pair, one electrical cycle completes in the same time as one mechanical shaft revolution.

Based on the combination and sequence of these three Hall sensor signals, we may determine the exact sequence of electronic commutation and apply it to energize the stator windings for appropriate motor operation.

The screen shot in Fig. 11 shows the Hall-effect sensor signals captured using the digital logic inputs of the Motor Drive Analyzer. The waveforms on the left (Digital1, purple) are the full 2-s captures of the three Hall-effect sensor signals, and the images on the right (Zoom of Digital1, yellow) are the 10:1 zooms of these same signals.

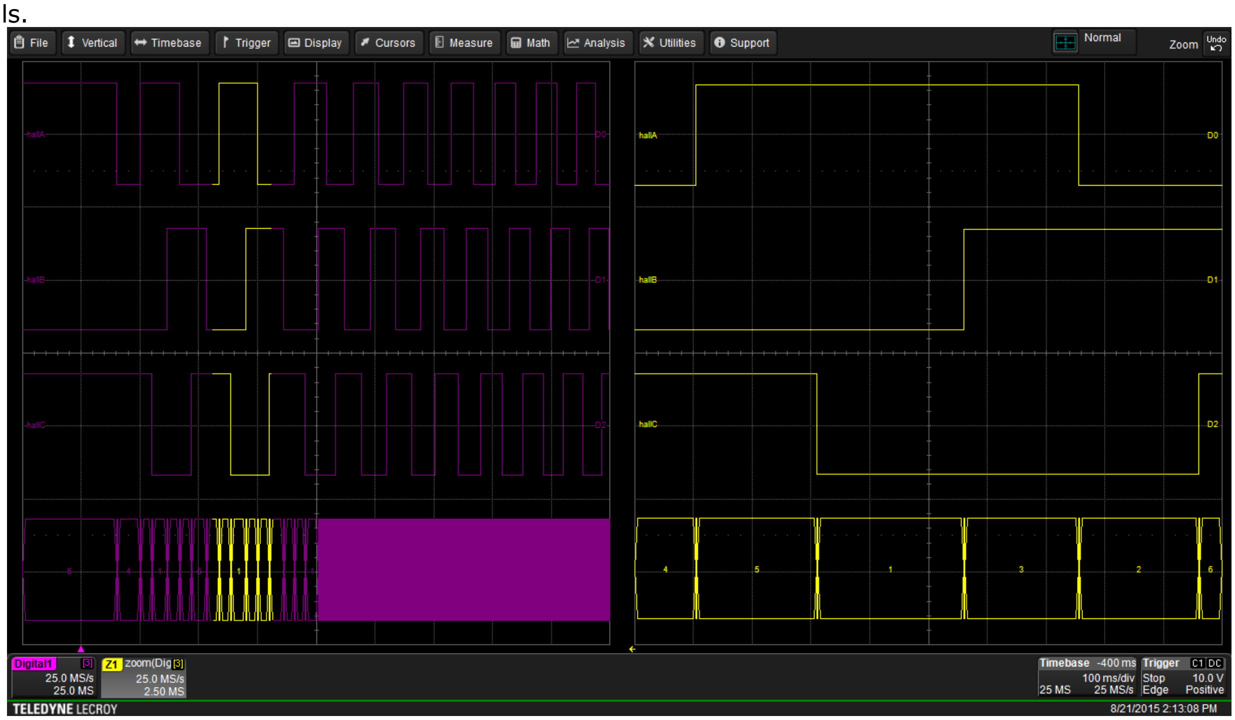

Fig. 11. Hall-effect sensor signals produced by a BLDC motor like that depicted in Fig 9 (one rotor-pole pair) are captured using the digital logic inputs of the Motor Drive Analyzer. The waveforms on the left (Digital1, purple) are the full 2-s captures of the three Hall-effect sensor signals, and the images on the right are zoomed versions of these signals.

Note that the Hall sensor three-bit signal codes in the screen image above (Fig. 11) are different than those shown in the earlier diagram (Fig. 10)—this is simply a reflection of the order of the codes. Regardless, there are six states, and a six-step commutation control system simply needs to know which of the six states the rotor is in at any given time.

Fig. 12 shows Hall-effect sensor signals (indicated as Digital 1, or purple trace) and line-to-reference voltage output envelopes (indicated as Channel 1, or yellow trace, Channel 2, or magenta trace, and Channel 3, or blue trace.) Note the correlation of the Hall-effect sensor transitions with the beginning or ending of PWM activity on a line-to-reference voltage waveform. Note also that any particular line-to-reference voltage waveform is only energized for four of the six different Hall logic states.

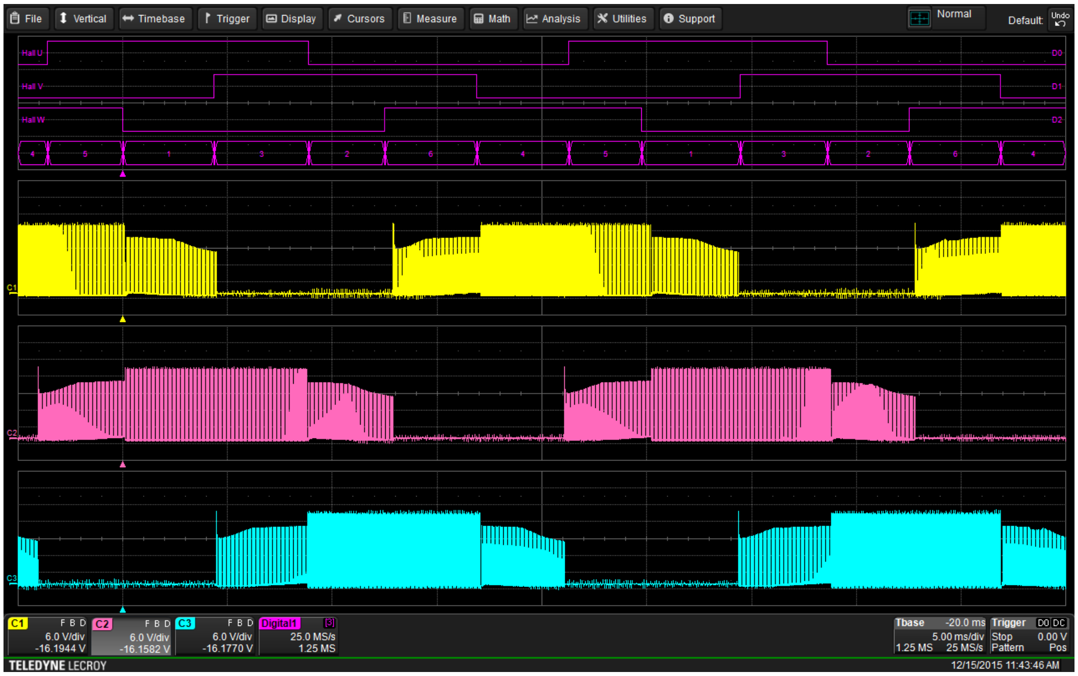

Fig. 12 Hall-effect sensor signals (Digital 1, purple trace) and line-to-reference voltage output envelopes (C1, or yellow trace, C2, or magenta trace, and C3, or blue trace) are shown for the BLDC motor measured in Fig. 11.

Fig. 13 is the same capture, but now showing voltage probed line-to-line.

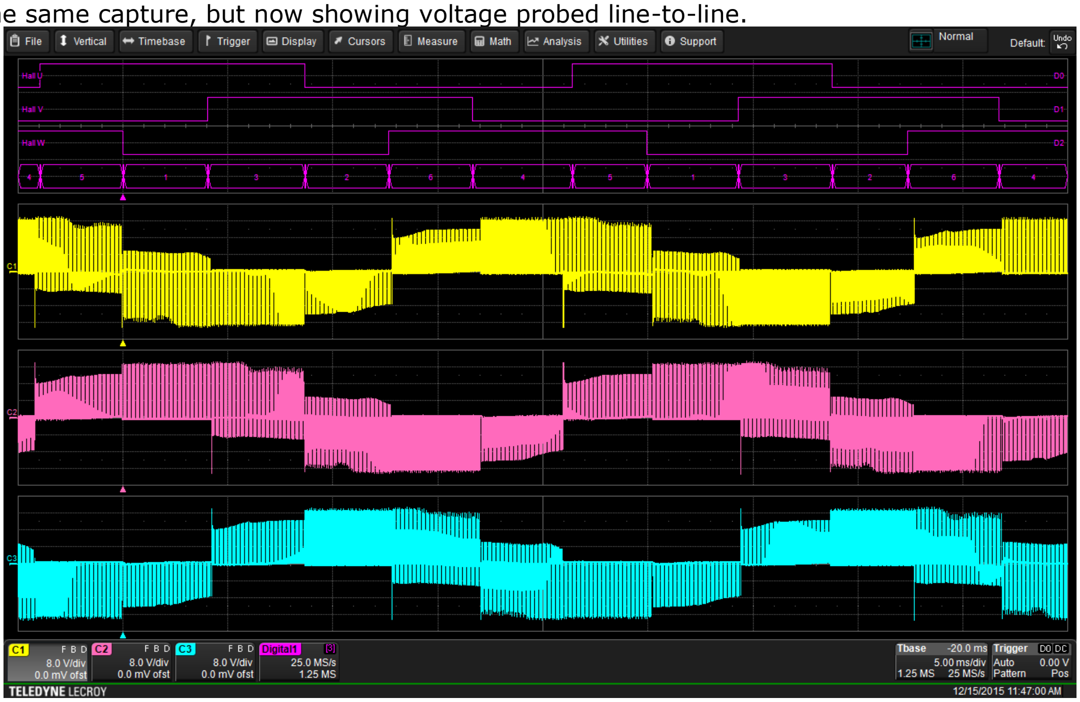

Fig. 13. Hall-effect sensor signals and voltage output envelopes are measured again, but with the voltage probed line-to-line.

In the above examples, the Hall effect sensors were spaced 120° apart from each other. However, if the three sensors are mounted 60° apart from each other, then we have placed the three Hall sensors on one side of the stator. There are still six unique three-bit transitions, so the operation is essentially the same, but there is 60° separation of the rising edges of the Hall-sensor signals at the beginning of the Hall cycle as depicted in Fig. 14.

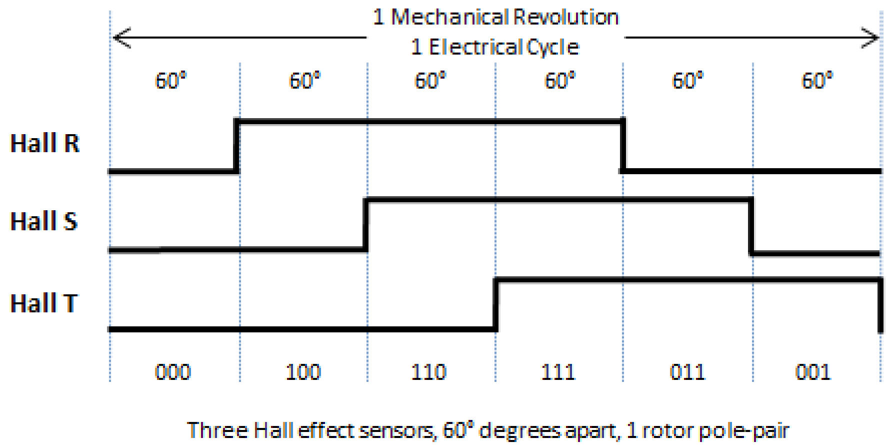

Fig. 14. Hall effect sensors may be placed 60 degrees apart. As was the case with the more widely spaced sensors, one electrical cycle is completed in the same time as one mechanical shaft revolution when there is a single rotor-pole pair.

When there are "N" rotor-pole pairs, there are "N" electrical cycles per mechanical shaft revolution. Fig. 15 shows the case for two rotor-pole pairs.

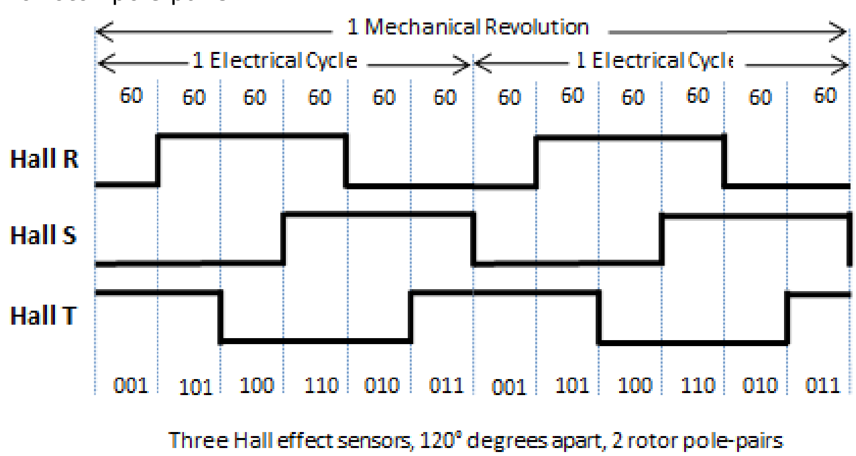

Fig. 15. With two rotor-pole pairs, two electrical cycles of the Hall effect signals will be completed in one revolution of the motor shaft.

Speed can be calculated from the Hall-sensor signals. Fig. 16 shows another example of Hall-effect sensor signals captured using the digital logic inputs of the Motor Drive Analyzer. But in this case, a plot of shaft speed is also shown.

The waveforms on the left in the Mechanical tab (Digital1, purple) are again full 2-s captures of the three Hall-effect sensor signals. Immediately to the right are zooms of these signals (Z1, yellow).

On the far right in the Speed tab is a waveform plot of various values of speed over time as we start a BLDC motor and run it up to speed with an applied load. At the bottom is the Numerics table that shows an average speed value for the full 2-s acquisition. An enlarged view of the Numerics table appears in Fig. 17.

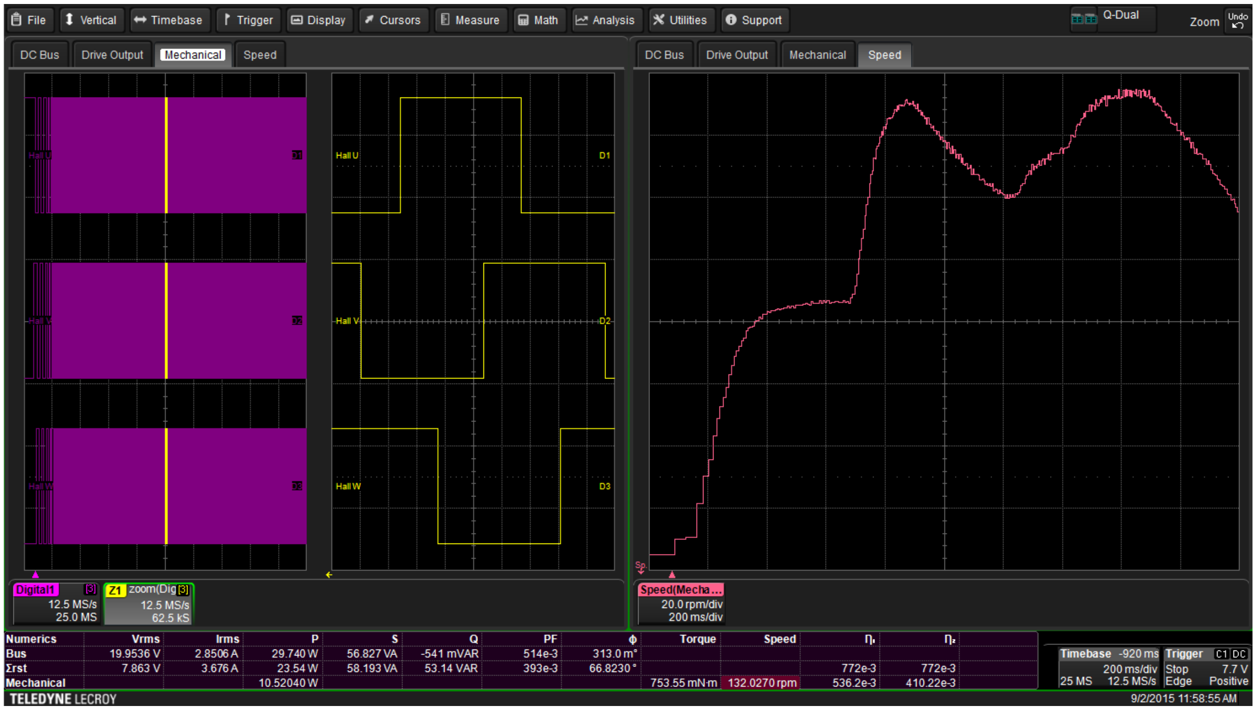

Fig. 16. Hall effect sensor signals (shown on the left) captured by the MDA are used to calculate the speed of the rotor.

Numerics	Vrms	Irms	P	S	Q	PF	Φ	Torque	Speed	η_1	η_2
Bus	19.9536 V	2.8506 A	29.740 W	56.827 VA	-541 mVAR	514e-3	313.0 m°				
Σrst	7.863 V	3.676 A	23.54 W	58.193 VA	53.14 VAR	393e-3	66.8230°			772e-3	772e-3
Mechanical			10.52040 W					753.55 mN·m	132.0270 rpm	536.2e-3	410.22e-3

Fig. 17. An enlargement of the numerics table from the previous figure shows motor power measurements and calculations as well as the calculated values for motor speed and torque.

Fig. 18 shows the setup for converting the Hall-sensor data to a speed value, taking into account the gearing between the motor and the shaft.

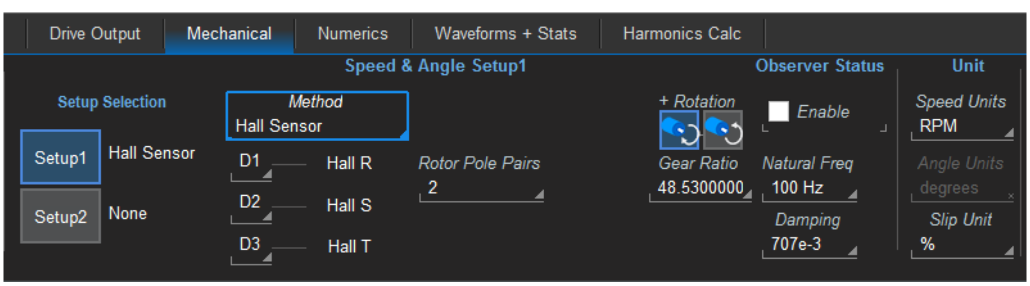

Fig. 18. Configuration of MDA settings for calculating motor speed from Hall sensor data.

Quadrature Encoder Interface (QEI)

QEIs are commonly used as a low-cost method to measure speed and angle, especially during the research and development phase as they are simple to connect to a shaft and implement in a control system. In this case, three digital pulses (A, B and Z, or the Index pulse) are used to define speed, direction and absolute position.

The QEI utilizes two digital signals (A and B) that are 90° out of phase to communicate a two-bit pulse sequence N times per shaft revolution. A third digital signal is used to communicate position information once per revolution. This third signal is the "Z" index pulse signal. This type of sensor is also referred to as an "incremental encoder" since it provides information on incremental, but not absolute, rotor shaft position (Fig. 19.)

The A and B signals together form four unique binary AB pulse patterns, and the sequence of pulse patterns is different for different rotational directions. The QEI can be constructed so that the "A" signal rising edge can lead the "B" signal, or viceversa.

Rotational direction can be conveyed based on the order of the digital AB sequence (for A leading B they are, in order, 00, 10, 11, 10 for a "positive" rotational direction). However, rotational direction is arbitrary, so the user must also define in the QEI setup interface which rotational direction represents positive.

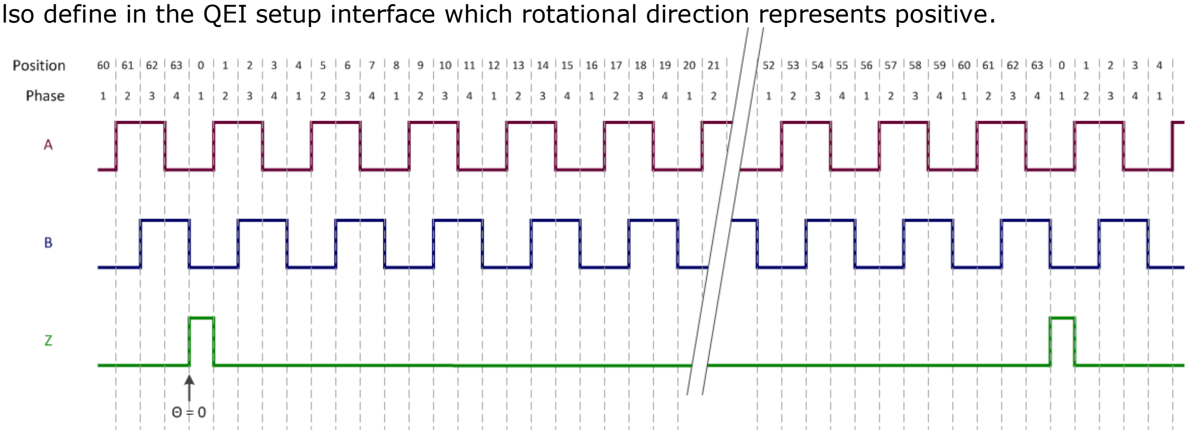

Fig. 19. With a QEI, the three digital pulses (A, B and Z, or the Index pulse) are used to define speed, direction and absolute position of the rotor. The A and B, which are 90° out of phase ("in quadrature") communicate a two-bit pulse sequence N times per shaft revolution. The Z index pulse signal is used to communicate position information once per revolution.

The unique two-bit (AB) pulse patterns are referred to as the QEI phases, which proceed through the binary sequence 00, 10, 11, 01 for positive shaft rotation. In this hypothetical encoder, there are a total of 16 repetitions of the phase sequences, or 64 pulses/revolution (ppr). There are multiple AB pulse pattern sequences per shaft rotation. The Z index pulse occurs once per revolution (once every 64 pulse transitions). While it could be used directly for speed measurements, it lacks enough resolution, especially at low speeds, to be useful.

The image in Fig. 20 shows a QEI signal captured with a Motor Drive Analyzer. The QEI A, B, and Z signals are digital, but in this case we have used analog channels to acquire them (digital inputs available with the Motor Drive Analyzer mixed-signal option can also be used, and normally would be used to conserve analog channels for other uses. However, viewing these signals in analog form, allows you to see all the interference on them before you use digital logic MSO inputs. By understanding the voltage levels, noise and interference on the signals, you can set up the MSO threshold level settings correctly.)

Z4 (green) and Z7 (red) (both in the top left grid) show a 100-ms capture of the QEI A and B signals. Z8 (orange, bottom left grid) shows the Z signal. To the right is a zoom of these signals so that more details are seen.

With QEI signals, the Motor Drive Analyzer calculates both speed and angle values and displays them as waveforms as shown in Fig. 21. Note that the angle tracking observer is applied in this case to reduce the speed measurement variation to approximately ±10 RPM in a nominally 1000 RPM steady-state measurement.

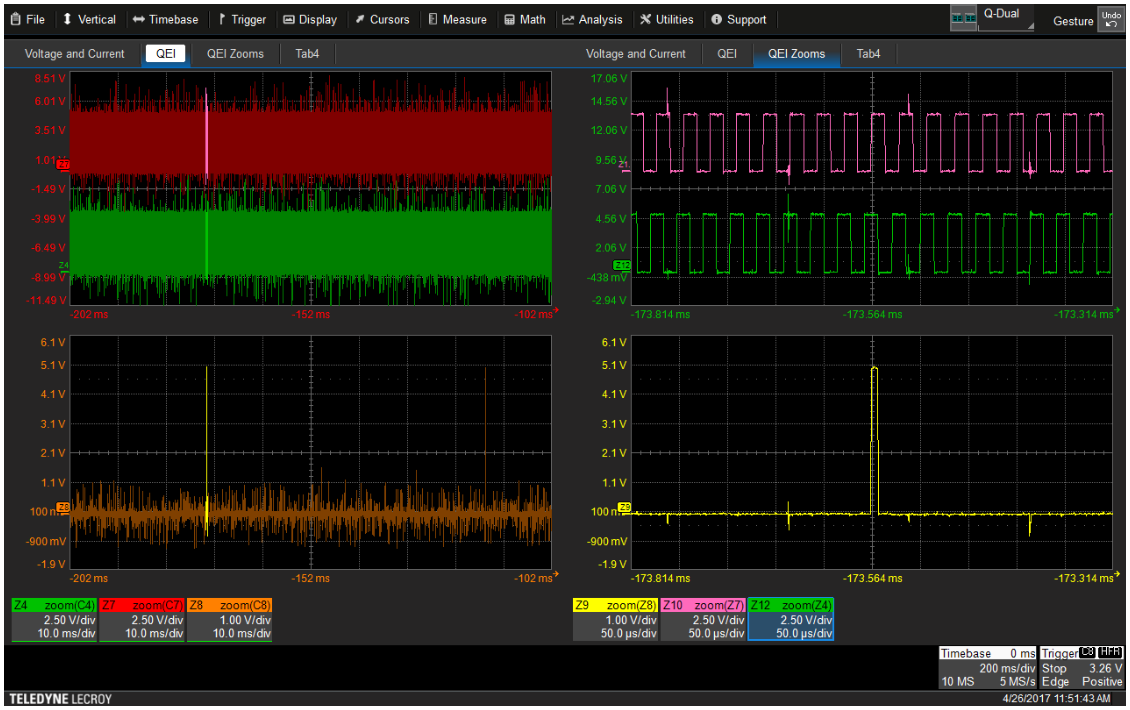

Fig. 20. A, B, and Z signals from a QEI acquired using the analog channels of an MDA. 100-ms acquisitions of these signals are shown on the left side of the display and zoomed versions (over 0.5 ms) are shown on the right side.

Fig. 21. The MDA calculates speed and angle values from QEI signals, displaying the results as waveforms as well values in the Numerics table.

The measurement values in Fig. 21 are enlarged in Fig. 22.

Numerics	Speed1	Angle1
Mechanical	1.037798 krpm	187.2353111 °

Fig. 22. A closeup of the Numerics table from the previous figure shows the mean values of speed and angle for the captured waveforms.

Fig. 23 shows the setup for converting the QEI data to a speed and angle value, including the use of the angle tracking observer filter.

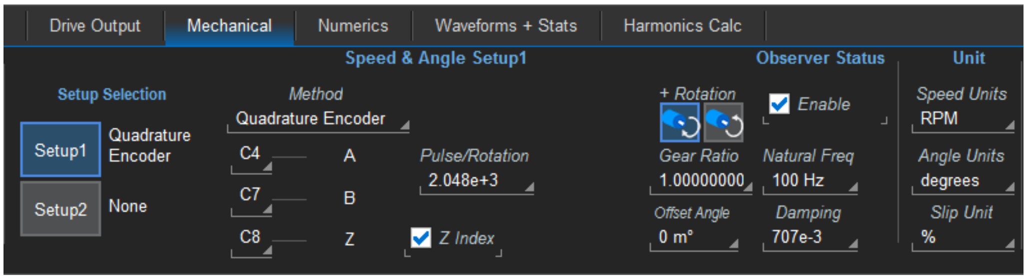

Fig. 23. Configuration of MDA settings for calculating motor speed and angle from QEI data.

Note that we may convert the calculated QEI shaft angle to a rotor magnetic pole field electrical angle by entering a value for the offset angle (offset of the rotor magnetic pole field electrical angle compared to the QEI shaft angle). It is useful to know the rotor electrical field angle for analyzing advanced vector FOC control systems, but it is unnecessary for speed or direction sensing.

Other Speed Sensors And Sensing Methods

To reduce sensor costs and/or provide more reliability, sensorless techniques or a variety of other sensors are often utilized, as described below.

- Back EMF on the motor winding can be calculated, and the period of the signal along with knowledge of the number of stator pole pairs and rotor pole pairs can be used to calculate shaft speed. This is a fairly simple process for a permanent-magnet-rotor motor, but becomes more complicated for an ac induction motor given the slip between the rotor and the stator.
- Speed data can be embedded in digital form in a variety of different serial data signals for delivery to the control system. The control system then decodes the serial data information to extract the speed data.
- A variety of lower-cost sine/cosine analog sensors may be used. These sensors do not require an applied excitation frequency, and the sine and cosine signals are not amplitude modulated (as with the resolver). Speed, direction and position (angle) are calculated from an arctangent calculation from the sine and cosine signals. These are commonly referred to as SinCos encoders. NXP Semiconductors has released an encoder that uses a similar approach. It is named the KMZ60 and is specifically geared towards automotive applications.

Angle Tracking Observers

Motor drive control systems engineers often use angle tracking observers to provide rotor speed estimations at a better resolution than would otherwise be achieved, and at far greater resolution than the excitation period (resolver), the Sin/Cos period (SinCos or KMZ60 encoders), or the digital switching frequency (QEI or Hall Sensor) can provide.

Additionally, the angle tracking observer provides smoothing of the speed calculations through use of an integrator and proportional-integral (PI) controller. These capabilities are necessary in order to provide appropriate control capabilities for more-complex control systems (e.g., vector FOC).

The angle tracking observer is essentially nothing more than a second-order phase-locked loop (PLL) implemented as a software algorithm in the control system.

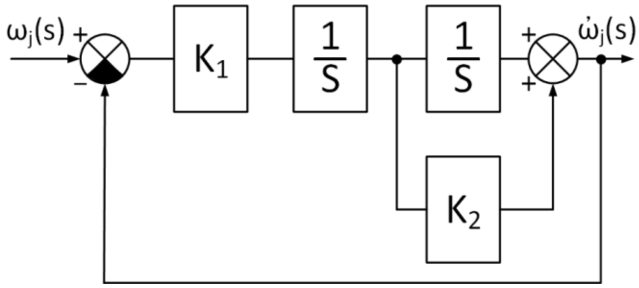

Fig. 24. An angle tracking observer implements the transfer function shown here in software.

Here $\omega_j(s)$ is the instantaneous angle value input to the Angle Tracking Observer and $\dot{\omega}j(s)$ is the instantaneous angle value output. The system shown above is a second-order system, and the transfer function T(s) of the system is expressed as follows:

$$T(s) = \frac{\dot{\omega}(s)}{\omega(s)} = \frac{K_1(1 + K_2 s)}{s^2 + K_1 K_2 s + K_1}$$

The transfer function of a general second-order system G(s) is

$$G(s) = \frac{{\omega_n}^2}{s^2 + 2\zeta\omega_n s + {\omega_n}^2}$$

where ω_n is the natural frequency in rad/s and ζ is the damping factor. Solving for K1 and K2 leads to the following:

$$K_1 = {\omega_n}^2$$
$$K_2 = \frac{2\zeta}{\omega_n}$$

The Teledyne LeCroy Motor Drive Analyzer includes this software algorithm, and it may be applied to Resolver, SinCos, KMZ60, Hall sensor, and QEI speed calculations. The setup is shown in Fig. 25, and we can see that a user simply enters the Natural Freq(uency) and Damping factor, as shown.

Fig. 25. Configuring the MDA for use of the Angle Tracking Observer algorithm.

These two values define the second-order system response that provides the filtering (“smoothing”) to the speed calculations.

Angle Tracking With Digital Encoders

An example of the angle tracking observer applied to a digital Hall sensor method speed calculation is shown in Fig. 26. The Speed1 trace (yellow) has the angle tracking observer applied whereas the Speed2 trace (magenta) does not. You can see that there is more resolution in the speed trace with the angle tracking observer applied and less variation due to the filtering of the observer.

Fig. 26. Angle tracking observer applied to Hall sensor digital signals.

The example in Fig 27 is the angle tracking observer applied to a short record capture (a 200-µs zoom of a 100-ms capture) of a digital QEI. The Speed1 trace (orange, top grid) has the angle tracking observer applied (Natural Frequency = 100 Hz, Damping Factor = 0.707) whereas the Speed2 trace (magenta, top grid) does not. Again, you can see that there is more resolution in the speed trace with the angle tracking observer applied and less variation due to the filtering of the observer.

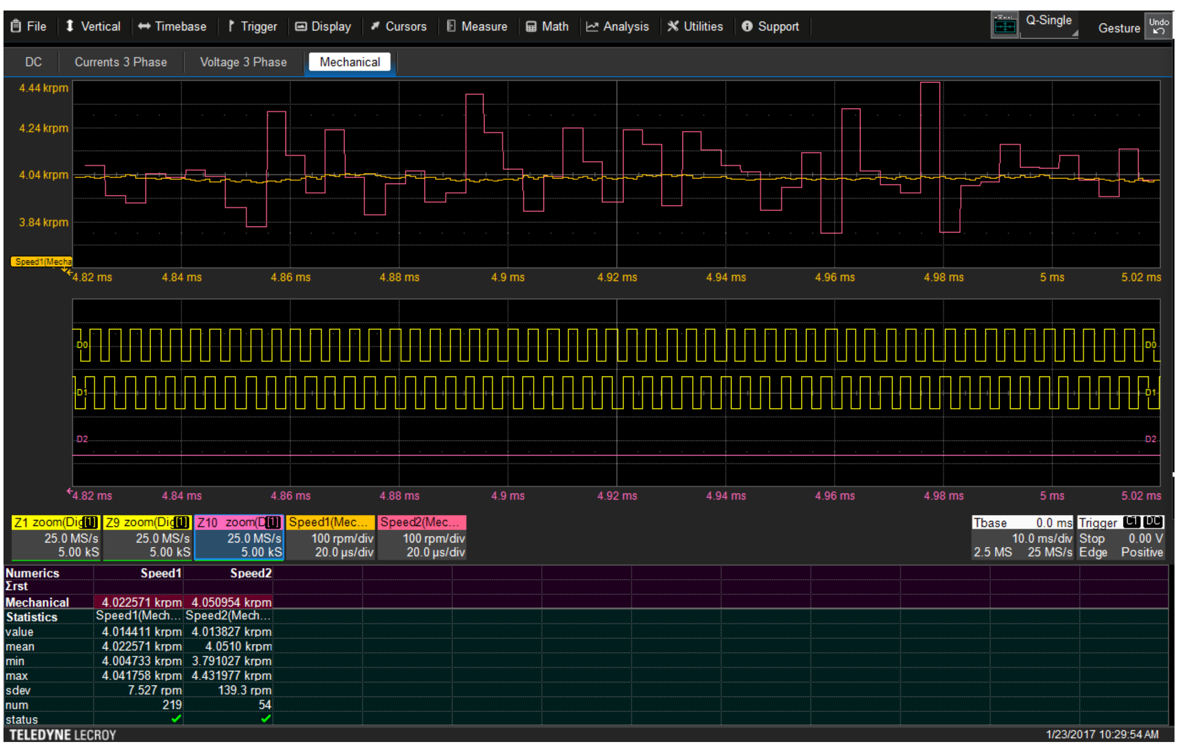

Fig. 27. Angle tracking observer applied to QEI digital signals.

Fig. 28 displays the same calculation as shown above, but for the full acquisition of 100 ms. Note that the Speed2 calculation (without the angle tracking observer applied) has significantly more variation in the measurement than the Speed1 calculation (with the angle tracking observer applied), especially near the Z index (angle reset) pulse.

Also, with the angle tracking observer settings described above, there is a startup filter time of ~20 ms. This would normally not be something seen in a motor drive control system since the filter is applied in real-time to acquired data, but it is present in the acquire and post-process approach used in a digital oscilloscope. This startup filter time can be ignored in the Motor Drive Analyzer using a Zoom+Gate to a location after the angle tracking observer filter has settled.

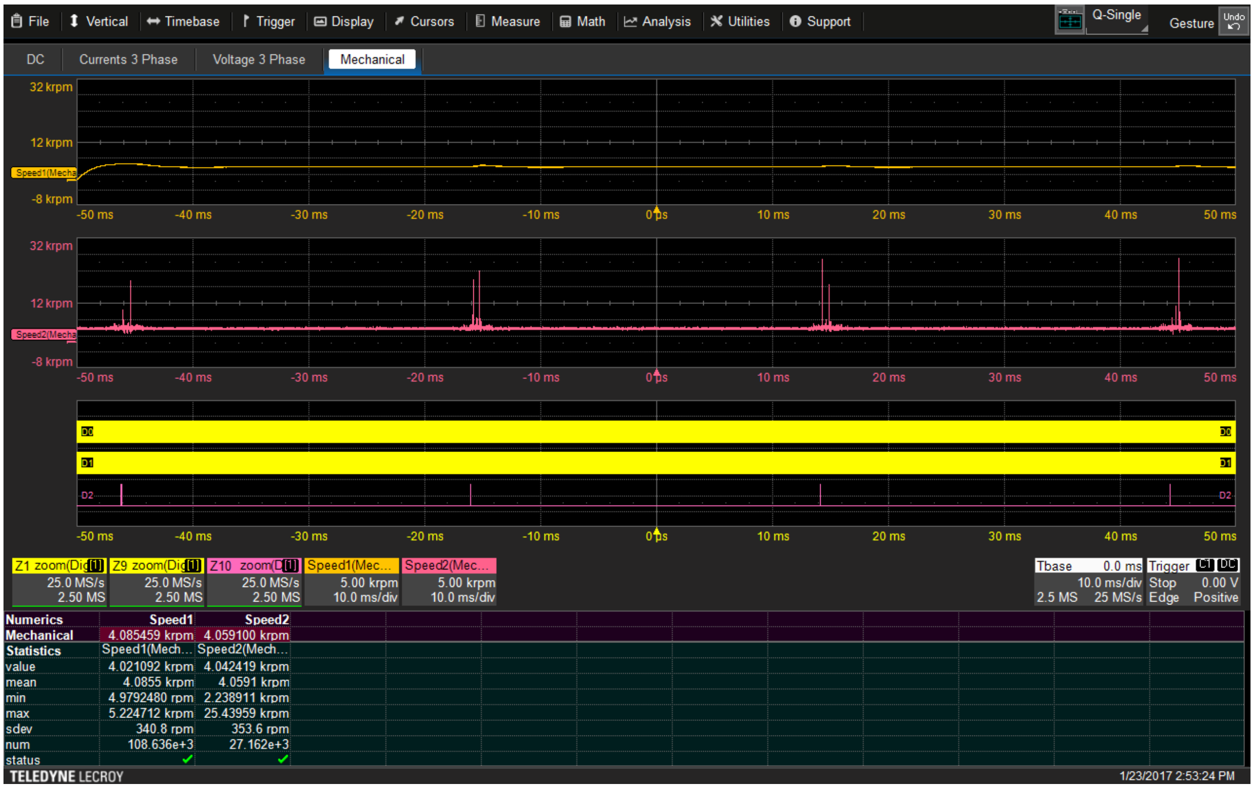

Fig. 28 Angle tracking observer applied to QEI digital signals for full 100-ms acquisition.

Angle Tracking Observer With Analog Encoders

Fig. 29 is an example of the angle tracking observer applied to a short record capture (a 20-ms zoom of a 2-s capture) using an analog Resolver method speed calculation of a Resolver Sin (Z4), Cos (Z3), and Excitation Frequency (Z7). The Speed1 trace (orange, top grid) has the angle tracking observer applied (Natural Frequency = 25 Hz, Damping Factor = 0.707) whereas the Speed2 trace (magenta, top grid) does not.

Fig. 29. Angle tracking observer applied to resolver signals for short (20-ms) acquisition.

Following in Fig. 30 is the same calculation as shown above, but for the full 2-s acquisition. Note the filter startup time in this example as well on the orange Speed waveform in the top grid.

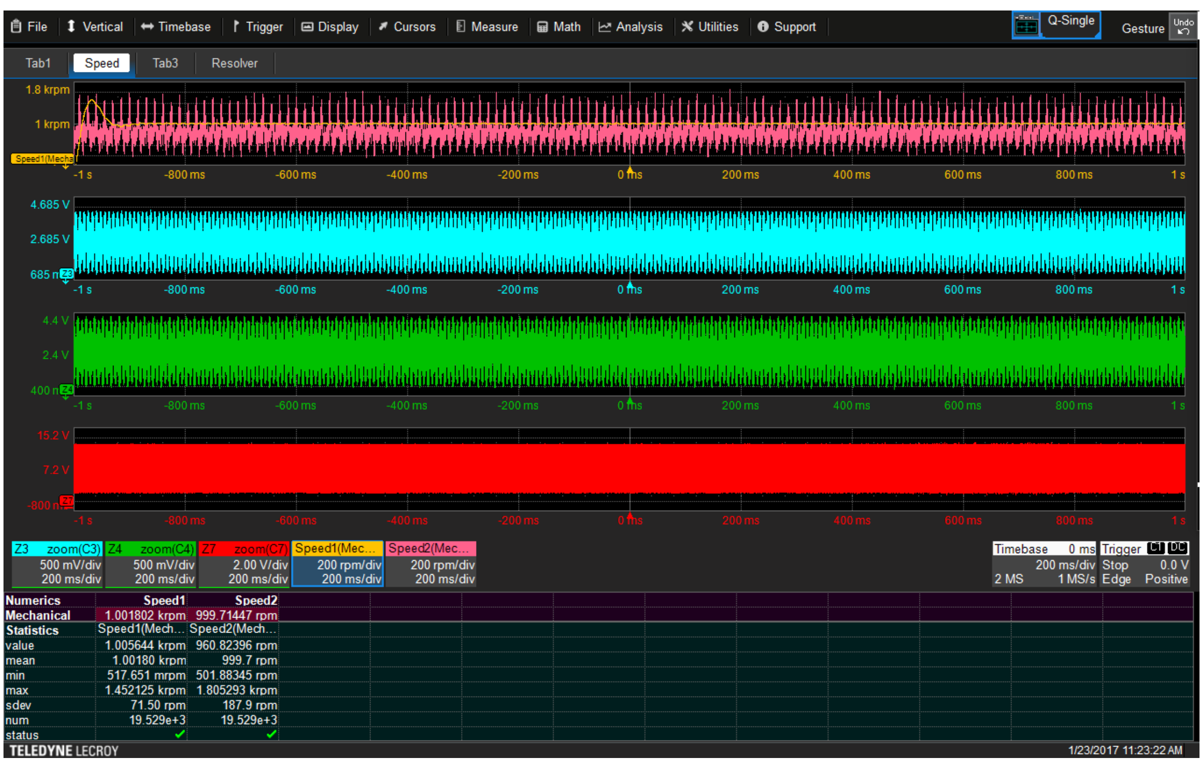

Fig. 30. Angle tracking observer applied to Resolver signals for full 2-s acquisition. This longer capture highlights the filter start-up time.

Conclusion

This section on motor shaft sensing concludes an article series that is intended to serve as a practical introduction to motor drives, introducing all the major aspects of the topic relevant to motor drive designers and others tasked with evaluating motor drive performance. This series sought to explain the subject conceptually and at a high level to provide engineers with the type of background information that is typically missing from other sources with the goal of paving the way for further study.

In explaining motor drive concepts, these articles have emphasized the relevant measurement techniques and calculations, and demonstrated how these can be performed using Teledyne LeCroy's Motor Drive Analyzer. In many cases, the same techniques may be applied to make similar measurements using power analyzers or instruments from other sources.

We conclude this series by once again referring the reader to part 1 where you'll find the full list of topics that were covered. For links to all 16 parts of this series, see How2Power's Introduction to Motor Drives. For a list of abbreviations used in this series, see the glossary below.

Glossary

AC – alternating current

ACAM – alternating current asynchronous motor

ACIM – alternating current induction motor

ACSM – alternating current synchronous motor

ANSI – American National Standards Institute

BLDC – brushless dc motor

C - collector

CSI - current-sourced inverter

DC – direct current

DTC - vector direct torque control

E - emitter

FOC – flux or field oriented control

G - gate

GaN – gallium nitride

GFCI – ground fault current interrupter

GTO - gate turn-on thyristor

IEC – International Electrotechnical Commission

IEEE – Institute of Electrical and Electronic Engineers

IGBT – insulated-gate bipolar transistor

IGCT- insulated-gate commutated thyristor

Lb-ft – pound feet

LCI – load-commuted inverter

MC - Matrix converter or cycloconverter

MOSFET – metal oxide semiconductor field effect transistor

N-m – Newton-meter

NPC - neutral point clamped topology

P – real power

PF – power factor

PMSM – ac permanent magnetic synchronous motor

PWM – pulse width modulation

Q – reactive power

QEI – quadrature encoder interface

Rad/s – radians per second

RMS – root mean square

RPM – revolutions per minute

S – apparent power

SCR – silicon controlled rectifier

Si - silicon

SiC – silicon carbide

SRM – switched reluctance motor

SVM – space vector modulation

SVPWM – space vector pulse-width modulation

THD – total harmonic distortion

VFD – variable-frequency (motor) drive

VSD – variable speed drive

VSI - voltage-source inverter

About The Author

Kenneth Johnson is a director of marketing and product architect at Teledyne LeCroy. He began his career in the field of high voltage test and measurement at Hipotronics, with a focus on <69-kV electrical apparatus ac, dc and impulse testing with a particular focus on testing of transformers, induction motors and generators. In 2000, Ken joined Teledyne LeCroy as a product manager and has managed a wide range of oscilloscope, serial data protocol and probe products. He has three patents in the area of simultaneous physical layer and protocol analysis.

His current focus is in the fields of power electronics and motor drive test solutions, and works primarily in a technical marketing role as a product architect for new solution sets in this area. Ken holds a B.S.E.E. from Rensselaer Polytechnic Institute.

For further reading on motor drives, see the How2Power Design Guide, locate the "Power Supply Function" category, and click on the "Motor drives" link.