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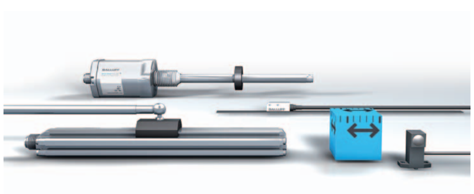
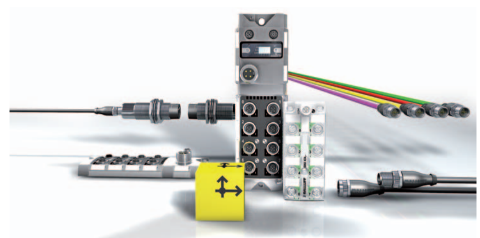
Motion Control Primer

Direct load position sensing with secondary feedback encoders





White Paper

White Paper

Position sensing primer

Direct load position sensing with secondary feedback encoders

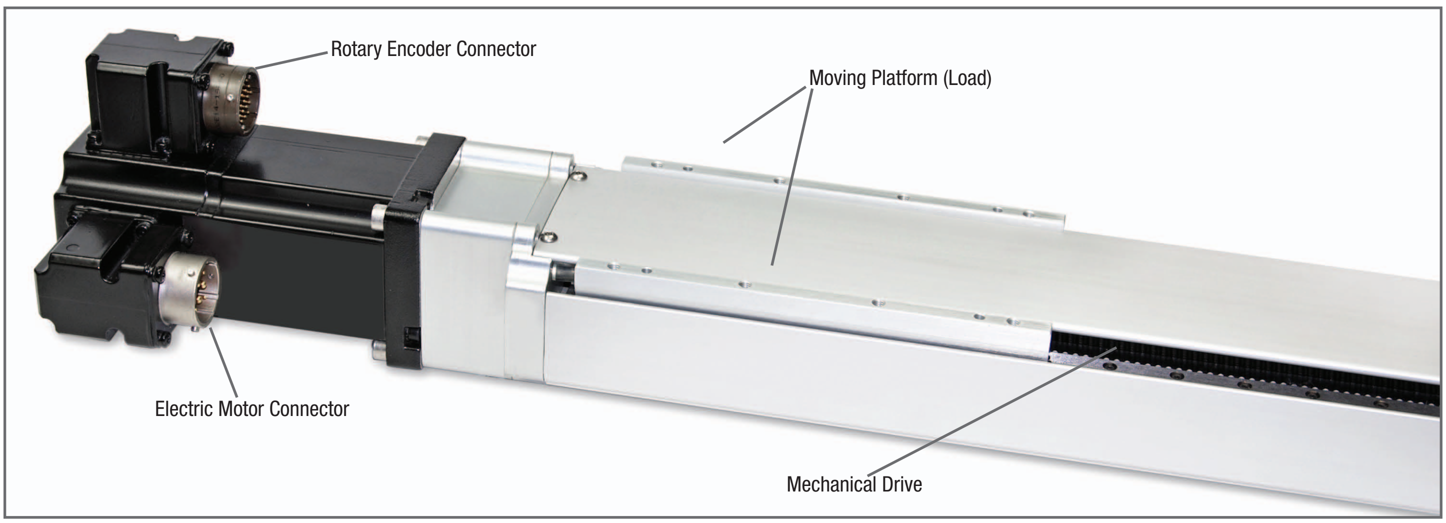
In closed-loop motion control systems, direct load monitoring using secondary feedback encoders eliminates common sources of position error — mechanical backlash, non-linearity, and hysteresis — and saves money along the way.

Motion control fundamentals

In the field of automation, a motion control system consists of mechanical hardware coupled to a prime mover, the operation of which is governed by a computerized controller that compares the command position to the indicated load position. Typically, the indicated load position comes from a rotary shaft encoder or linear position encoder. In response to a difference between the command position and indicated load position, the controller generates a drive signal that is fed to the device that regulates the speed and direction of the prime mover — for example, an electronic amplifier driving a servomotor.

This process of reading position, comparing it to the command position, and then driving the prime mover until it is positioned correctly is called closed-loop motion control. Besides position, other controlled variables such as velocity (the mathematical derivative of position) or force can also be measured. With respect to position and velocity, the accuracy of the controlled motion – from the perspective of the load — is highly dependent upon how closely the indicated load position matches actual, real-world load position. The indicated position is always a facsimile of the actual load position. Due to various error-inducing factors, the indicated load position never exactly matches the actual load position. The nature of the induced position errors depends on the architecture of the position encoder and how it interacts with mechanical drive hardware.

Typical rotary encoder-based positioning systems



The indirect load monitoring system showin in this application includes an electric motor directly coupled to a rotary shaft encoder, which acts as the load position sensor. In this setup, although the rotary encoder accurately indicates the drive motor's shaft position, the true standard of measurement is not the rotary encoder, but the drive system itself.

For electric, closed-loop motion control systems, common system architecture features an electric motor as the prime mover directly coupled to a rotary shaft encoder as the load position sensor. The load may be connected to the electric motor through a variety of mechanical elements such as acme, lead, or ball screws, rack-and-pinion systems, or toothed sprockets with toothed drive belts.

In this architecture, the true standard of measurement is not the rotary encoder, but the drive system itself. The rotary encoder accurately indicates (within its specifications) the drive motor's shaft position. To implement closed-loop position control, an assumption must be made that X revolutions of the motor/encoder result in Y units of displacement at the load. For example, it may take 1,800 revolutions of the motor for the load to travel 12 in., which can also be expressed as 1,800 rev/12 in. = 150 rev/in.

Factors contributing to inaccuracy in rotary encoder systems

The relationship between motor revolutions and load displacement is only an average, calculated figure. The actual relationship along any given segment of the positioning system is dependent on the drive system's mechanical precision: A high quality leadscrew may closely follow specified revolutions per inch, whereas a lower quality screw may deviate more substantially from the nominal value. Any deviation away from the ideal linear relationship between revolutions and displacement is called nonlinearity.

In addition to that of the screw itself, there are other sources of nonlinearity, such as mechanical compression or tension of the leadscrew under dynamic conditions of acceleration and deceleration, as the load inertia resists the impulses of the drive system. This type of loading can also dynamically stretch drive belts and cause dynamic torsional distortion of drive shafts. More dynamic motion and heavier loads magnify how much these factors contribute to overall system nonlinearity and resulting errors in load position or velocity.

Depending on the application's accuracy requirements, thermal expansion and contraction of the drive system creates position deviations that must be quantified and compensated to maintain performance tolerances. Even in zero-backlash drive systems with little or no mechanical play, reversal of drive direction can impart a significant mechanical hysteresis error that arises from frictional forces and drive component compliance in shafts, leadscrews, thrust bearings, and so on.

Cost drivers in rotary encoder systems

The precision of this type of motion control architecture is at its peak when the system is brand new. However, as the system wears in and tolerances open, accuracy begins to deteriorate and continues to decline over the system's lifetime. This means that the system must be designed to deliver excess initial system performance in order to guarantee specified performance over time, resulting in a higher initial system cost. Furthermore, because motion-control system accuracy is determined by the quality and precision of the mechanical drive system — and not the rotary shaft encoder — it follows that tighter accuracy specifications force tighter specifications on the drive mechanism, imposing a cost premium for higher-end mechanical components.

Effects of mechanical wear and tear over time in rotary encoder systems

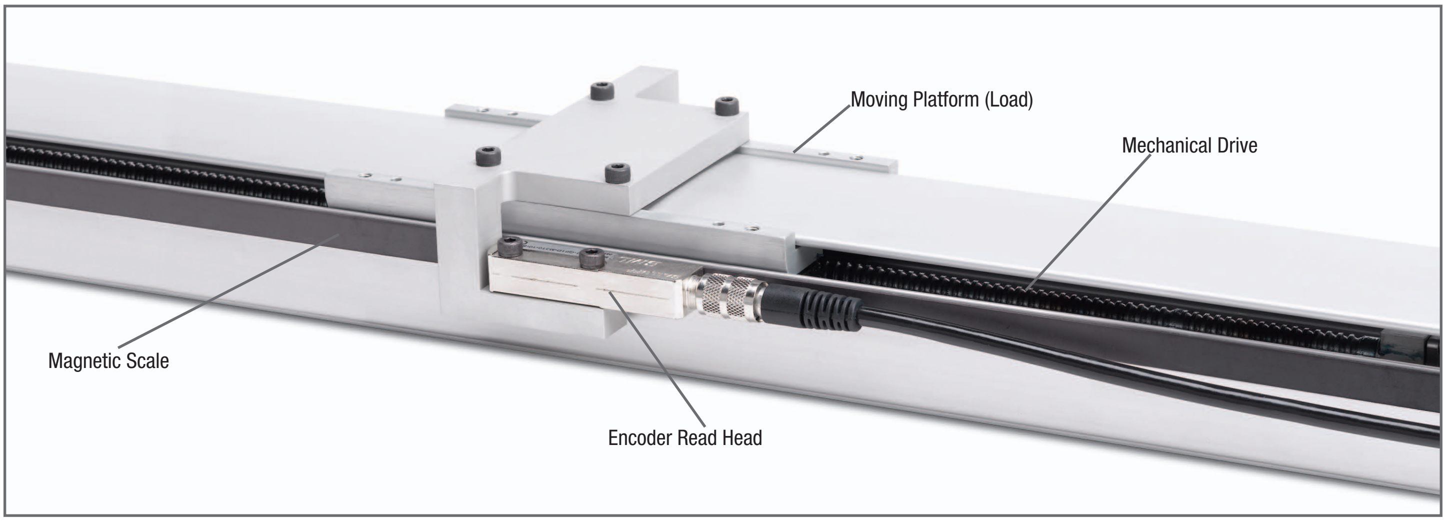
Once the system is in operation, mechanical failures can result in large indicated position errors that might go undetected until bad parts are produced. For example, a drive belt might slip or jump a tooth, a shear pin might break, or a rack-and-pinion gear might wear enough to slip out of synchronization. In these cases, the shaft-mounted rotary encoder has no way of knowing that the nominal relationship between shaft revolutions and load position has been completely invalidated.

Motion control system architecture defines limits of system performance

This motion control architecture in which a rotary encoder is coupled to the shaft of the drive motor is an example of indirect load monitoring. By locating the position encoder at the back end of the drive system instead of at the load itself, the system accuracy is inherently limited by the imperfections of the mechanical drive system.

A better way: linear encoders as secondary feedback

An alternative architecture for closed-loop motion control systems eliminates or minimizes the influence of any nonlinearity that may exist in the mechanical drive system. By simply relocating the primary position data collection point from the motor shaft to the linear motion axis itself, drive-system stack-up errors can largely be ignored. (Bear in mind, however, that extremely sloppy mechanisms are always hard to tune.) In this arrangement, motor shaft revolutions do not need to be directly proportional to load position, because the linear encoder is now directly reporting load position. This system architecture - where a secondary linear encoder is located along the controlled motion axis - is an example of direct load monitoring.



A system architecture where the linear encoder is located along the controlled motion axis is an example of direct load monitoring. By simply relocating the position data collection point from the motor shaft to the linear motion axis itself, drive–system stack–up errors can largely be ignored. In this arrangement, motor shaft revolutions do not need to be directly proportional to load position, because of the linear encoder is now directly reporting load position.

Advantages of direct load monitoring using secondary feedback

Direct load monitoring offers several economic and performance benefits. For starters, the indicated load position is not affected by mechanical factors such as backlash, dynamic compression or tension, drive wear and tear, or rotation reversal hysteresis. Nor is linearity compromised by the quality or accuracy of the leadscrew or other drive system components. By relieving the mechanical drive system of the burden of maintaining overall system accuracy, less precise or lower cost drive mechanisms can be employed as part of the original design. Because wear and tear no longer degrades system accuracy over time, there is no need to build in excessive upfront performance in order to guarantee accuracy over the system's life expectancy: System designers can save costs by more closely matching initial performance specifications to long-term performance expectations.

With direct load monitoring, the accuracy of the indicated load position is largely a function of the linear encoder's accuracy. Linear-encoder specifications can be closely matched to application requirements, eliminating unnecessary cost. Direct load monitoring architectures are also largely immune to drive failures that may result in catastrophic position errors. Even if a belt slips or a gear breaks, the indicated position coming from the linear encoder still closely represents actual load position.

Each encoder plays to its strengths: accurate reporting of speed and position

The motion controller now has two independent sources of dynamic feedback: the rotary encoder mounted on the motor, and the linear encoder mounted on the moving load. The rotary encoder still provides an excellent source of data regarding the speed and direction of the motor itself. This is very important information that is needed by the motion controller to ensure precise control of position and velocity of the driven load. At the same time, the secondary feedback provided by the linear encoder provides rock-solid position data as well as speed and direction. The combination of these two data sources allows the motion controller algorithms to deliver motion that is smooth, accurate, responsive, and adaptable to varying loads.

Monitor mechanical drive wear and tear

By comparing the indicated positions of the rotary and linear encoders to one another, the motion control system can monitor mechanical drive wear and tear over time. As the drive begins to exhibit increasing play and slop, the amount of deviation between the two readings will increase and provide valuable information for preventive maintenance and predictive failure. If and when catastrophic mechanical failure occur, the large differential between the rotary and linear encoder readings provides instant notification of the problem.

A note on thermal effects

Heat affects all mechanical positioning systems. Indirect load monitoring systems are subject to position error from thermal growth or contraction of the leadscrew. Controllers can partially correct for these effects with known expansion-coefficient values, but direct load monitoring does not require this compensation; as motion axis components (and the work piece itself) expand with increasing temperature, so does the linear encoder. If the thermal expansion coefficient of the linear encoder closely matches the coefficient of the drive components and work piece, no relative position error is introduced, and the system is self-compensating with respect to temperature. To this end, many linear encoders are delivered with metallic base materials that closely match the expansion characteristics of the metal surfaces on which they are mounted.

Summary of key points

Indirect load monitoring – primary feedback only

Motor-mounted rotary encoder only

- Rotary encoder itself is accurate
- Rotary encoder correctly reports shaft position
- Shaft position is only an estimate of actual load position
- Accuracy affected by mechanical factors such as backlash, leadscrew quality
- Thermal effects must be compensated
- System accuracy decreases as wear and tear increases
- Initial accuracy limited by precision of drive mechanism
- High-precision drives increase system costs

Direct load monitoring - primary + secondary feedback

Motor-mounted rotary encoder + load-mounted linear encoder

- Load position is directly reported
- Supplements standard motor-mounted rotary encoder
- Backlash, non-linearity, and hysteresis are eliminated as sources of inaccuracy
- Constant position accuracy over time regardless of drive wear and tear
- Accuracy of indicated position is independent of actuator drive precision or backlash
- Can implement less precise, less expensive mechanisms without loss of accuracy
- Immune to catastrophic position errors caused by broken or slipped drive belts, damaged or worn leadscrews/gear-boxes, and broken shafts or couplings

Visit the Balluff website to learn more about linear and rotary encoder products and applications: **www.balluff.us/bml**

About the author

Henry Menke is the position sensing marketing manager for Balluff North America, based in Florence, KY.
Read Henry's blog posts at: **www.sensortech.wordpress.com**

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USA
Balluff Inc.
8125 Holton Drive
Florence, KY 41042
Phone: (859) 727-2200
Toll-free: 1-800-543-8390
Fax: (859) 727-4823
E-Mail: balluff@balluff.com

Canada
Balluff Canada, Inc.
2840 Argentia Road, Unit #2
Mississauga, Ontario L5N 8G4
Phone: (905) 816-1494
Toll-free: 1-800-927-9654
Fax: (905) 816-1411
E-Mail: balluff.canada@balluff.ca

Mexico
Balluff de México SA de CV
Anillo Vial II Fray Junípero Serra No. 4416
Colonia La Vista Residencial.
Querétaro, Qro. CP76232
Phone: (++52 442) 212-4882
Fax: (++52 442) 214-0536
E-Mail: balluff.mexico@balluff.com

www.balluff.com