

IMPROVING THE RELIABILITY  
OF HYDRAULIC CYLINDER  
POSITION SENSORS

**White Paper**

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#### Introduction / Executive Summary

Magnetostrictive linear position sensors are the dominant technology for hydraulic cylinder position feedback. They are preferred over alternatives due to their high accuracy, wide variety of electrical interfaces, signal stability across temperature variation, wear-free operation, and tolerance of shock and vibration. This makes them popular in a wide range of industrial hydraulic applications for smart cylinders and servo-hydraulic systems.

Despite the inherent ruggedness of the sensors, highly demanding industrial applications exist that push and sometimes exceed the limits of survivability for standard product offerings. Compromised life expectancy can result in premature sensor failure and/or preventive maintenance intervals that are shorter than desired.

Fortunately, continuous design innovation has resulted in the development of specialized product variations that deliver much longer service life and more reliable operation for longer periods of time under adverse operating conditions. Best practices for installation and mounting can also help alleviate exposure to the most damaging effects of harsh application environments. This white paper will discuss common industrial application challenges and propose potential solutions that can enhance sensor reliability and extend life expectancy.



Hydraulic cylinder with position sensor installed

#### Adverse Operating Conditions

##### Heat

High temperatures are a fact of life in many industrial processes, such as the steel-making process. Areas such as the coke oven battery, blast furnace, electric arc furnace, oxygen converter, continuous casting line, and hot rolling line create a hot ambient environment that can destroy electronics. Solid-state electronic components are stressed by elevated temperatures and can fail at much higher rates than they would at room temperature.

Ambient heat can affect sensors through three mechanisms:

1. **Conduction** (direct transfer from the mechanical mounting)
2. **Convection** (circulating hot air impinging on the sensor housing)
3. **Radiation** (line-of-sight infrared heating of the sensor housing at a distance)



Sensors applied in the steel industry must withstand high ambient temperatures in production areas



##### Three Steps to Protect Against Heat

Start by evaluating the installation to see what can be done to mitigate the exposure of the sensor to the heat. To combat conduction, try to locate the sensor as far as possible from the heat source. If practical, install thermal breaks (insulators) to isolate the sensor mechanically from direct contact with hot objects. Convection can be alleviated by installation of guards or deflectors to block impingement of hot air onto the sensor housing. Often these same guards will aid in blocking radiated infrared energy as well, keeping in mind that at some point that energy is going to get through and be re-radiated on the back side. In some cases, the heat source is intermittent, such as a passing red-hot slab of steel on rollers, so the heat only needs to be blocked for a few seconds to protect the sensor.

Next, be sure to specify the right kind of cylinder position sensor for hot applications. Standard cylinder sensors typically have a maximum specified temperature rating of 75° C (167° F), but enhanced variants are available that can withstand up to 100° C (212° F). Don't forget that the connecting cable needs to be up to the job as well. Many standard cable materials will melt or break down quickly at higher temperatures, so look for specialized cable jacket materials such as PTFE that can withstand up to 200° C (392° F). Another strategy is to insert a double-ended cordset between the sensor and the home run cable that is designed to be sacrificial. If this short sacrificial cable becomes damaged, it can be quickly replaced without the time-consuming task of pulling a new home run cable.

Finally, it may be that the hot environment is just too severe for any electronics to survive for very long. In these cases, place the sensor in a protective enclosure designed for air purge or water jacket cooling.

## Extreme Cold

In some industries, particularly oil and gas, operations are conducted in arctic or subarctic regions where temperatures can fall to  $-40^{\circ}\text{C}$  ( $-40^{\circ}\text{F}$ ) or below. At these temperatures, polymers intended to remain pliable such as O-rings, gaskets, cable insulation and outer jackets, and sensor element damping materials can become embrittled. Semiconductor materials start to lose conductivity and circuits can behave unpredictably.

Special hydraulic cylinder sensors are available that are designed to operate as low as  $-50^{\circ}\text{C}$  ( $-58^{\circ}\text{F}$ ). These products feature polymer materials designed and specified to operate down to those temperatures. To combat electronic malfunction under these conditions, the manufacturer may specify that power should remain applied to the electronics at temperatures below  $-40^{\circ}\text{C}$  ( $-40^{\circ}\text{F}$ ). The heat dissipation of the electronics themselves serves to keep them within normal operating limits.



Cylinder position sensors operating in frigid arctic conditions to monitor pipeline valve actuators.

## Physical Impact

Standard cylinder position sensors are typically constructed with a stainless steel flange and an extruded-aluminum housing secured by a couple of screws. In most applications, this type of sensor will last a long time. However in cases where the housing may be exposed to physical impact, such as a falling log in a lumber mill, standard sensors can easily be damaged.

There are three basic approaches to improving a sensor's chances of surviving a mechanical impact:

- 1. Guard.** Many cylinder manufacturers can provide accessory guards for cylinder sensors. These are essentially lengths of steel pipe, attached to the cylinder end cap, that cover the sensor. A disadvantage is that they often have to be removed in order to service the sensor, and all too often they are mistakenly or intentionally left off after the service procedure, leaving the sensor vulnerable to impact.
- 2. Embed.** Compact cylinder sensors are available that can be embedded inside the cylinder. Thus, the rugged cylinder itself protects the sensor inside from damage. These sensors are usually called embeddable types. Often installed in welded cylinders for mobile hydraulic applications, they are entirely suitable for stationary industrial applications as well.
- 3. Upgrade.** Cylinder sensors with especially robust housings provide an upgrade path from standard types. Thread-in types are available for retrofit applications, as are even more robust bolt-in types (the cylinder must be prepared accordingly by the cylinder manufacturer).



Cylinder position sensors installed in a lumber mill. Protective cap is missing from unit at right.

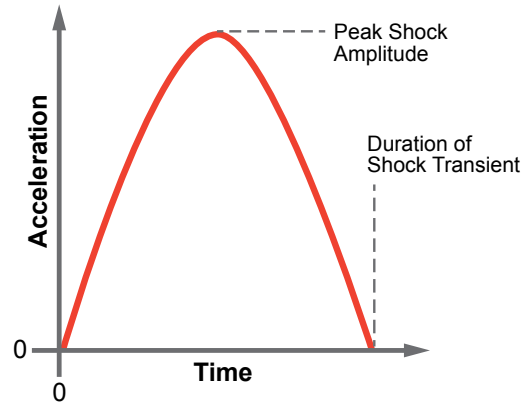


Cutaway view of hydraulic cylinder, showing embedded linear position sensor installed inside the protective enclosure of the cylinder itself.

Built to take a beating: rugged stainless steel cylinder position sensor housing, retained in place by six bolts.

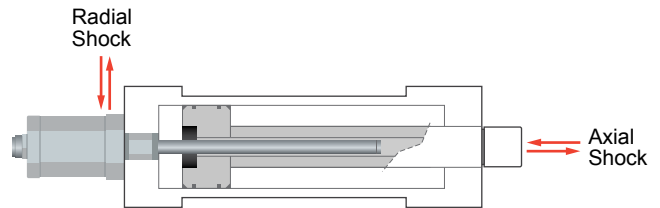
## Shock

Many industrial hydraulic cylinder applications involve large forces and heavy loads that can generate substantial amounts of shock under normal and/or abnormal conditions. Shock is defined as a rapid acceleration or deceleration transient, and can occur axially or radially relative to the cylinder position depending on the application.



Shock Transient: Acceleration vs. Time

Typically, hydraulic cylinders deliver or absorb axial shock along their linear axis of operation. Trunnion-mounted cylinders often generate radial shock, for example infeed rollers coming down on a log in a lumber mill, as they pivot in their mounting.



Shock can occur in the axial and/or radial directions

If an application is suffering from a high sensor failure rate due to shock, the first step is to determine if the hydraulic control system can be optimized to reduce the generation of shock. For example, can the motion control profile be tuned to deliver less violent acceleration or deceleration? Can the motion profile be adapted to enable softer starts and stops? The key to reducing shock is to reduce the peak amplitude of the G-forces and/or stretch out the time of the transient so that the acceleration gradient is less severe. A 100 G peak shock delivered over 6 milliseconds is less severe than a 100 G peak shock delivered within 3 milliseconds.

Once the application has been evaluated and optimized to minimize shock generation in the first place, the next thing to do is look for sensors with enhanced shock specifications. The minimum specification should be 100 G, with preference given to products rated up to 150 G. For even more severe applications, consult the sensor manufacturer regarding specially engineered versions.

Don't forget that the extra mass of a sensor-mounted quick-disconnect connector can sometimes be a vulnerability under severe shock. Combat broken connectors with so-called "pigtail" or "inline" connectors that have a flexible cable coming out of the sensor that goes to a quick-disconnect a few inches or feet away.

## Vibration

Vibration is also ever-present from motors, rollers, and moving materials. When combined with heat or thermal shock due to ambient temperature fluctuations, vibration can rapidly age electronic components and internal connections, leading to early failure.

Vibration mitigation can be difficult or infeasible for cylinder position sensors in most cases, so enhanced sensor design is required to improve sensor survivability when exposed to extended high-vibration environments. An effective design and testing methodology for achieving sensors that can withstand extended exposure to vibration is called HALT or Highly Accelerated Lifetime Test.

Products undergoing HALT are subjected to accelerated aging during their development in order to uncover weak points early so that they can be eliminated. The samples are subjected to ultra-low and ultra-high temperature soaking as well as rapid, extreme temperature changes. The temperature range can extend from  $-100\text{ }^{\circ}\text{C}$  to  $+200\text{ }^{\circ}\text{C}$  with a temperature gradient of up to  $70\text{ K/min}$ . This is followed by vibration testing up to maximum levels of  $50\text{ G}$ . The repeated cycles of temperature and vibration testing is continued until the test unit finally reaches its limit and is destroyed. The goal of the design team is to extend the period of time until ultimate failure as long as possible.

Look for sensors with excellent specifications for vibration. EN 60068-2-6 provides a good standard of  $20\text{ G}$  with a frequency sweep from  $10\dots 2000\text{ Hz}$ .



HALT testing chamber and data logging equipment.

## Liquid Ingress

Applications where there is a continuous exposure to liquids like water, coolants, and oils will eventually overcome the housing gaskets found on many standard sensors rated to IP67 or less. Standard sensors are designed to withstand liquid ingress for a specified period of time, but are not rated for constant immersion or exposure to wet conditions.

The photo below was taken in a rolling mill and shows a blue plastic cover installed over a position sensor in an attempt to keep falling water from entering the sensor housing.



Production workaround to combat water ingress problems: blue plastic cover installed over a sensor in a steel rolling mill.

As always, mitigation is an effective approach; try to locate sensors out of wet areas if practical, and/or provide effective splash guards. When exposure to liquids can't be avoided, select sensors with enclosures rated IP68 or IP69K. IP68 means that the manufacturer is offering immersion protection beyond IP67 (consult the manufacturer for details) and IP69K means that the sensor is rated for pressurized washdown. Some sensor housings are hermetically welded to provide a 100% leak-proof assembly.

Be aware the cable can represent a vulnerability to liquid ingress. If the cable jacket is cut and liquid enters, it can be transported inside the cable and end up inside the sensor housing. It's a good idea to install protective tubing over the cable to ensure that it remains intact in case of incidental contact or abrasion in the application.



Hermetically-welded sensor housing rated to IP69K. Shown with cable protection system installed to prevent cable damage and subsequent liquid ingress via the cable entry.

## Corrosion

Chemicals present in the environment can lead to problems with sensor housing corrosion, in particular, aluminum housing components can be compromised by prolonged exposure to corrosive elements. Common examples include road salt, seawater and airborne sea spray, and acidic food juices, among other contaminants.

Here is an example of the kinds of corrosion problems that can occur. On the failed unit (right), the red RTV silicone sealant was a plant maintenance attempt to provide additional protection for the sensor. Despite the addition of external sealant, acidic water worked its way under the silicone and became trapped against the lower part of the housing. When the sensor failed and was pulled out for analysis, peeling back the layer of sealant revealed several holes had been eaten through the aluminum housing. The recommended housing material to alleviate most concerns about corrosion is stainless steel. For typical conditions, standard grades 303 and 304 stainless steel are sufficient.

In areas where salt or seawater is present, stainless steel grade 316L is preferred. Standard stainless steel is protected from corrosion by a thin layer of chromium III oxide that forms at the surface. Some ions, such as chloride ions found in salt water, can strip away this protective layer and expose the underlying steel to corrosion. 316L stainless steel is formulated to resist attack by chloride ions.



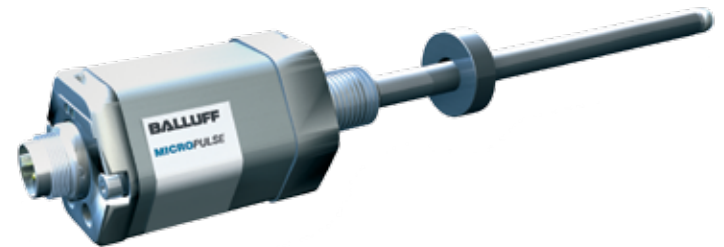
**Standard aluminum-housing position sensor destroyed by exposure to acidic water near a scale cracker in a steel rolling mill.**



**Stainless steel housing provides additional corrosion protection compared to standard aluminum housings.**

## High Cylinder Pressure

Standard cylinder position sensors are rated for hydraulic pressures up to 600 bar / 8700 psi, which is sufficient for most applications. However some compact mobile hydraulic systems run at higher pressures, as do heavy-lift systems used for example in civil engineering projects. Special high pressure cylinder sensors are available rated up to 1000 bar / 14,500 psi to ensure that the system remains safe and operational at elevated system pressures. Be aware that outer diameter of the pressure tube surrounding the sensor element is necessarily larger: 12.7 mm vs. standard units at 10.2 mm, thus requiring a larger gun drill in the cylinder rod and a target magnet with a larger inside diameter. Also keep in mind that the hydraulic port size of M22x1.5 is larger vs. the standard 1/4"-16 UNF or M18x1.5. These differences in mechanical details need to be communicated to the cylinder manufacturer at the time of specifying and ordering, otherwise a standard sensor-prepped cylinder may be delivered.



**Cylinder sensor with high-pressure rod rated to 1000 bar / 14,500 psi.**

## Redundancy and Rapid Repair

To combat the consequences of sensor failure in critical applications, system designers have a number of options to help keep operations running despite a failure, or to get failed units back on line quickly. Three common approaches include:

- 1. Redundant sensors.** This method involves utilizing two, three, or even four sensors operating in parallel. When one sensor fails, the others continue functioning. In schemes involving more than two sensors, voting in the controller can be used to determine which sensors are delivering valid position signals and which one is out of synch with the others. Typically, the primary sensor will be installed in the cylinder. The redundant sensor or sensors will be installed externally in mounting bracketry design to hold the sensor in place and connect the target magnet to the moving portion of the equipment.



Externally mounted cylinder position sensor used to provide signal redundancy.

- 2. Redundant sensor outputs.** Specialized cylinder position sensors are available with two or three entirely separate position sensors contained in a single sensor enclosure. Each sensor is provided with its own separate connector. The advantage is ease of installation in a standard cylinder port, without the need for external mounting and bracketry. A theoretical disadvantage is dependency on a single target magnet inside the cylinder and a single pressure tube. Any loss of the magnet or damage to the pressure tube can take down all channels together; however in practice such an occurrence would be extremely unlikely.



Cylinder position sensor with three redundant outputs. This assembly is actually three entirely separate position sensors sharing a single enclosure.

- 3. Rapid repair.** Sensors are available with modular electronics that can be quickly removed in the event of failure, while leaving the pressure tube in place in the cylinder. This eliminates safety concerns such as hot oil spilling onto maintenance workers, loss of hydraulic fluid and resulting clean-up/containment, and the potential for entry of contaminants and air into the hydraulic system.



Cylinder position sensor with user-replaceable electronics module. Hydraulic flange and pressure tube remain installed in cylinder while electronics package is exchanged.

Another rapid repair strategy: install a sensor with redundant outputs, but connect only one channel for control. Cover the unused connectors to protect them while not in use. If the control channel fails, simply move the connecting cable to another channel and resume operations. The sensor unit with a failed channel can then be scheduled for removal and repair during a planned preventive maintenance shutdown.

## Conclusion

Premature and/or frequent cylinder sensor failure is not a situation that needs to be tolerated in harsh industrial applications. Careful attention to application conditions and matching sensor selection to application requirements can alleviate or eliminate issues related to sensors failing. When failures do eventually occur, strategies such as redundant sensors, sensors with redundant outputs, or sensors designed for rapid repair can help maintain production uptime through higher sensor availability or minimization of downtime with modular construction designed for fast electronics replacement.

## About the Author



Henry Menke is the Marketing Group Manager for Sensing Products at Balluff, Inc. in Florence, Kentucky. In addition to over 20 years of experience in the industrial automation industry, Henry has a degree in Electrical Engineering Technology from the Milwaukee School of Engineering and an MBA from Xavier University. His professional passion is identifying pervasive sensor-related problems that result in lost productivity and excessive costs to manufacturers, and helping to develop new solutions and approaches that can enhance manufacturing uptime and increase the productivity of capital investments.

## About Balluff

### Rugged Control Components from Network to Sensor

Balluff specializes in delivering dependable, rugged and precision products for industrial sensing, networking, and identification to help prevent downtime and eliminate errors. We are a complete system and component supplier, offering industrial network and I/O products for use outside of the control cabinet. We add value to automated systems by providing a wide range of enabling technologies that unlock hidden productivity potential.

Our products include a complete line of sensors, transducers, ID systems, and connectivity products. Our sensor lines include photoelectric, inductive, capacitive and magnetic, as well as other more specialized sensor products to fit virtually any sensing application.



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