THE PRESSURE TO PERFORM IN HYDRAULIC SYSTEMS & CIRCUITS

Hydraulic systems are a critical component to industrial and commercial transportation systems such as construction vehicles and equipment.

During the past two decades, the hydraulic industry has benefited from advances in electronics, the widespread adoption of IoT (Internet of Things), technology cost reductions, and component miniaturization. Additionally, the hydraulic industry has seen an increase in challenges while transitioning from traditional pressure switches to pressure sensors and transducers.

These challenges include increases in pressure, higher operating temperatures, deployment into hazardous and harsh environments, and pressure transients. These are challenges for designers and system integrators and may result in project delays or field reliability issues if not addressed appropriately. These pressure measurement devices have also evolved, from the sensing element and overall mechanical package to its electronic output signal and the signal conditioning.

In this paper we will review the technology behind pressure sensors and transducers, the common mechanical challenges these sensors face and how TE Connectivity's (TE) M9100 pressure transducer performs in these challenging environments.

SENSING TECHNOLOGY – A LOOK INSIDE YOUR SENSOR

From the outside, pressure transducers all look relatively the same, yet the core sensing element varies greatly among sensor manufacturers. One of the most common economical and technologically feasible approaches is to use a strain gage as the sensing element to transfer the mechanical strain the pressure induces on a diaphragm into an accurate and repeatable electrical output signal. TE uses its Microfused strain gage technology in a Wheatstone bridge configuration to transform the strain into a voltage output signal.

TE designed the sensing element as a single machined component integrated with the threaded port. This optimized design provides a robust signal from the sensing element and provides great levels of overpressure and burst performance.

TE uses a glass bonding process to fuse the silicon strain gages to the metal port. The gages are optimally positioned to properly measure the strain as the pressure changes. Industry proven wire-bonding processes are used to make connections between the gages and signal conditioning electronics.

Competing technologies in the hydraulic pressure sensor market such as thin-film deposition, thick-film and ceramic-based technologies utilize separate diaphragms with low sensitivity sensing elements. These technologies require additional welds in the fluid paths, internal O-rings, or require additional processing steps that can drive long supply chain lead times.

Alternate technologies may require high strains in their sensing element to compensate for low sensitivity. These high strains along with multi-piece construction can result in reduced long term stability and durability.

The Microfused strain gage technology at TE has been proven in high- volume production for decades, has low risk of supply chain disruption and delivers a robust single-piece fluid connection, reducing the risk of internal sensor failures and other mechanical challenges.

MECHANICAL CHALLENGES

As pressure transducers are installed as part of a hydraulic system, various mechanical challenges should be addressed and recognized within the design. Below are the typical areas within hydraulic systems that system designers need to consider as part of the design process:

- Operating Pressure
- Pressure Spikes
- Proof Pressure
- Fluid Connections
- Burst Pressure
- Vibration/Mechanical Shock
- Pressure Fatigue
- Environmental Durability

Each of these concerns are addressed through the sensor design and validation. Over pressure ratings, burst pressure ratings, fatigue analysis, and the use of pressure snubbers are all part of the design process at TE and validated both through simulation and empirical testing.

Operating Pressure Range

Simply defined, this is the pressure range that requires system control or feedback. Under typical operating conditions, the system will always stay within this range. Pressures outside of this range normally don't require a measurement.

Proof Pressure

Often in system design there are pressure events that happen that exceed the needed measurement range but should not cause damage to the system. Typically, the expectation is that after an overpressure event, the system will return to normal function. TE specifies proof pressure as the pressure which may be applied to the sensing element without causing a permanent change in the output characteristic or accuracy of the pressure transducer.

Burst Pressure

There may be potential failure modes at the system level that could result in the system experiencing excessive pressures risking pressure containment failure. TE designs and validates their pressure transducers both theoretically and empirically to specify the minimum pressure that the sensor can experience without rupture.

Pressure Fatigue

Typical pressure fatigue is found in systems where there is a pump or valve that continuously results in pressure fluctuations in the system. These fluctuations vary in magnitude and frequency. A pump may create a high frequency pressure oscillation with very low magnitude, while a valve could result in a significant pressure change, but less frequently. In some cases, the opposite may be true.

It's impossible to predict every potential system behavior, therefore the TE's M9100 is tested from 0 to full scale pressure cycling up to 10M cycles and is theoretically validated to confirm stresses stay below the fatigue limit, providing essentially unlimited life within the operating range, and often times within the proof pressure range.

It should be pointed out that because TE's sensing element is much more sensitive than competing technologies, the stress level is so low that the pressure fatigue is not a concern.

Pressure Spikes

Possibly the most hidden challenge in a hydraulic system is the existence of very high frequency pressure transients, commonly referred to as "pressure spikes" and are sometimes referred to as the water hammer effect. A pressure spike may occur during valve actuation; imposed pressure waves due to system architecture, or the introduction of air into the hydraulic pump.

The pressure spike is typically characterized by an extremely fast increase in pressure (typically micro-seconds) to very high amplitudes (potentially 10X operating pressure). The speed of a pressure spike can be so fast that a typical pressure sensor may not be able to detect that the event has occurred. This phenomenon can, however, permanently damage the pressure transducer resulting in a permanent zero shift, cause failure of the sensor to respond to pressure or rupture the diaphragm causing the fluid to leak into the sensor housing.

Often customers do not have the proper equipment to properly identify pressure spikes in their system, yet the selection of a pressure transducer with the correct technology will help. TE's robust M9100 design and optional snubber reduce the potential failure modes caused by pressure spikes.

Fluid Connections

Another mechanical consideration is the connection into the hydraulic circuit. There are various threaded connection options that are popular amongst the global regions including SAE (North America), G-series (EMEA), and Metric (APAC). TE has long-standing experience with historical industry standards such as SAE J1926 or ISO 1179, and continues to keep pace with the changing requirements.

Each threaded connection also holds its own ratings; as high pressures become more common within the hydraulic industry, extra precaution should be taken to ensure the pressure transducer is properly rated, seated, and torqued.

Vibration/Mechanical Shock

Mechanical shock and vibration are traditionally paired together within the sensor industry. Pressure transducers are commonly exposed to both conditions within on and off-road applications due to the specific mechanical environment of the applications they're used in. From the high frequency vibration of a diesel motor to the shock of a forklift dropping a full load to the ground, these conditions require the pressure transducer to be immune from the adverse effects of "shock and vibe."

Environmental Durability

Environmental durability is critical to ensure any product can meet the extremes of the environment and provide years of reliable service. A pressure sensor needs to consider mechanical design and material choices to ensure compatibility and reliability over a lifetime of use, but also needs to consider the impact of these environmental conditions on the long-term performance of the sensor.

Now that we've reviewed the common mechanical challenges pressure sensors face, let's take a look at the rugged design of TE's M9100 heavy-duty pressure transducer designed to solve the mechanical challenges of critical hydraulic machinery.

RUGGED DESIGN

The rugged design and reliable performance of the M9100 pressure transducer addresses the pressure sensing needs of heavy-duty applications.

TE's M9100 sensor is one of the best-in-class for hydraulic durability. The M9100 was designed with both simplicity and durability in mind to meet or exceed the needs of the most rugged applications. Complex designs that require multiple circuit boards, internal wiring, and multiple soldered interconnects are typically more vulnerable to infant mortality and field reliability issues.

The M9100 is designed to be simple, compact, and durable by eliminating as many failure modes as possible. The pressure transducer achieves its compact footprint with a single PC board design. All solder joints in the sensor are well controlled through automated pick and place equipment and re-flow soldering. There are no hand solder joints or soldered interconnects inside the sensor and, there is no board stacking.

The single-piece machined stainless steel sensing diaphragm structure eliminates extra assembly steps such as welds and bonds. The construction yields a low degree of strain resulting in excellent proof, burst, fatigue, and pressure spike resistance resulting in lower risk of issues both during the design process and in the field.

The Microfused sensor design features an extremely thick diaphragm in comparison to other technologies. This allows the sensor to be more resistant to damage from pressure spikes and fully contain these pressure events. Further, TE's M9100 features an optional integral snubber which can further reduce the speed and amplitude of a pressure spike. The integrated design eliminates the need for a separate component.

The internal body of the sensor is sealed from the external environment with an O-ring. This design protects the internal components of the sensor from salt spray, humidity, higher pressure wash and submersion.

Compatibility with Heavy-Duty Connection Systems

The M9100 pressure transducer is fitted for large, durable connection systems like TE's DEUTSCH DT connector series, one of the best-in-class for ingress protection. The DEUTSCH connection system coupled with the robust sensor design results in a sensor that is designed from the ground up to allow the sensor to survive in a variety of harsh conditions and eliminates the risk that salt spray, humidity, dust, or water could penetrate the product, resulting in failure.

The materials chosen for the design exceed the operating temperature range of the product. Thermoplastic choice, adhesive choice, and the choice of electronic components (including an AEC-Q100 rated ASIC) contribute to the product's robustness to temperature extremes, sunlight, oxygen, or to typical chemicals found in heavy duty equipment applications.

M9100

M9100 PRESSURE TRANSDUCER PERFORMANCE

Hydraulic machinery and their components are required to function reliably while exposed to extreme conditions.

The core technology of a pressure sensor is a very complex electromechanical system. The intention of the pressure sensor is to convert pressure in a system into an electrical output. On the physical level the strategy is to convert a strain in a surface "the diaphragm" into an electrical output that is directly proportional to and is repeatable to the pressure applied. However, the complexity comes in as the elements used are susceptible to just about every other environmental influence.

Strain Gauge Technology

TE's strain gage technology, explained earlier is this paper, has been developed and optimized over decades to minimize sources of error and provide a highly sensitive and repeatable pressure output. This output signal can then be corrected and amplified with the use of an application specific integrated circuit (ASIC).

This ASIC corrects for errors induced by non-linear output and thermal errors and variations in supply voltage. This error correction simplifies the base definition of performance into a simple term called total error band. The total error band is the culmination of all remaining errors that the ASIC can't correct for (including part-to-part and batch-to-batch variation) and is defined as the maximum error the user will experience over the compensated temperature range.

The M9100 uses an AEC-Q100 qualified ASIC that contains diagnostic capabilities. The diagnostics confirm the sensor is working correctly and reduces the opportunity for an incorrect output signal.

The use of the total error band specification over a wide temperature range (-40°C to +125°C) simplifies the expectations on how the sensor will perform within the system. The ASIC is also responsible for the signal conditioning of the sensor, taking the signal from the silicon strain gages and converting it into an amplified analog signal.

While the ASIC corrects for repeatable errors, the same environmental effects can cause non-repeatable errors, the most prevalent being drift over time. Drift is defined as a time-based change in sensor output. This influence can come from a number of sources including changes in the mechanical strain in a diaphragm (creep or stress relaxation); physical changes in the sensing element due to electrical effects or mechanical effects, or changes in the resistivity of electrical connections, or protective gels. Pressure cycling, overpressures, temperature exposure, temperature cycling, and humidity can all contribute to this long-term drift.

TE's longstanding experience with Microfused strain gage technology and known contributors to environmental drift has allowed TE to optimize the design and processing to provide customers with a stable product. From concept to proof through validation testing, TE's Microfused strain gage is one of the best-in-class sensing technologies.

High EMI Protection

The electrical environment of equipment is becoming more complex as data is communicated within the equipment as well as around it. Sensors and transducers are exposed to increasing levels of electrical noise that can interfere with the signal if the sensor is not properly protected.

The M9100 is validated to ISO 11452-2 for radiated susceptibility allowing the product to survive nearby electrical noise and installation near EMI emitting components.

The M9100 is resistant to BCI (Bulk Current Injection) interferences up to 200mA per ISO 11452-4. Furthermore, a high level of electrical protection to the power supply makes the sensor more robust to poor power supply control and reduces the risk of system issues.

While it's recommended to design a wiring system that does not permit reverse connections, the M9100 can survive an overvoltage of up to 28 VDC, reversed power supply voltages of up to 16 VDC, and a shorted analog output to either V(+) or GND, all without experiencing damage. Please see the **M9100 datasheet** for a complete list of electrical test specifications the product has been validated to.

CONCLUSION

Hydraulic systems are a critical component of industrial and commercial transportation systems. The hydraulic industry has seen an increase in challenges while transitioning from traditional pressure switches to pressure sensors and transducers such as increases in pressure, higher operating temperatures, deployment into hazardous and harsh environments, and pressure transients within hydraulic circuits.

The rugged design and reliable performance of TE Connectivity's M9100 pressure transducer meets these challenges and addresses the pressure sensing needs of heavy-duty applications.

About TE Connectivity

TE Connectivity is a $12 billion global industrial technology leader creating a safer, sustainable, productive and connected future. Our broad range of connectivity and sensor solutions, proven in the harshest environments, enable advancements in transportation, industrial applications, medical technology, energy, data communications and the home. With approximately 80,000 employees, including more than 7,500 engineers, working alongside customers in approximately 140 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at **www.te.com** and on LinkedIn, Facebook, WeChat and Twitter.

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NORTH AMERICA	EUROPE	ASIA
Tel: +1 800 522 6752 customercare.frmt@te.com	Tel: +31 73 624 6999 customercare.lcsb@te.com	Tel: +86 0400 820 6015 customercare.shzn@te.com

te.com

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