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A High-Pressure Job

Karmit Sidhu discusses the crucial role pressure measurement plays in modern hydraulic systems.

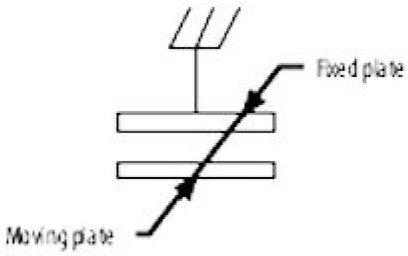
From sub-sea to aerospace applications, hydraulics plays a vital role in today’s economy. Hydraulics-based applications can be found in benign laboratories or harsh operating conditions that are prone to extreme temperatures, shock, vibration, Electro-Magnetic Interference (EMI), Radio Frequency Interference (RFI) and pulsations.

As electronic controls began to surface in the early 1970s, a new control system term ‘electrohydraulics’ entered the industrial world. These early control systems kick-started the industrial automation revolution. Over time, better sensing technologies, and the availability of low-cost microprocessors and controllers, accelerated the growth of hydraulic controls. In today’s modern hydraulic systems, pressure measurements play an important role in determining the health of the system by means of overall performance, safety and feedback. Depending upon the application, most modern hydraulic systems operate from 1,000 PSI (70 Bar) to 10,000 PSI (700 Bar); however, there are some that may go as high as 60,000 PSI (4,000 Bar). Pressure measurements can be done with a simple on-off pressure switch or an electronic pressure sensor, which offers a linear electronic output signal.

Today, electronic pressure sensors are fast-replacing pressure switches due to their flexibility and performance; however, there are certain factors that must be addressed to ensure performance and reliability in hydraulic applications. Pressuresensing technologies, sensor packaging, hydraulics transient protection and EMI/RFI protection must be considered carefully for each application.

Sensing the Pressure

The two main technologies used for pressure sensing are capacitive and piezoresistive. Capacitive technology employs gap-sensing by means of a capacitance change between two plates; one fixed and other moving as shown in Fig.1. This capacitor is normally connected to a complex electronic circuit, which will convert the capacitance to an output signal such as 1–5 V or 4–20 mA. Since the change of capacitance is in the range of one pico Farad to one femto Farad, the electronic circuitry is placed closely to the sensing plates to minimise stray capacitance. This tends to limit the operating temperature of the sensor, as there is a short distance between the media and capacitor.



$$\Delta C = \frac{\Sigma_o \Sigma_r A}{d}$$

Σ_o = permittivity of free sapce (a vacuum) 8.854×10^{-12}

Σ_r = dielectric constant of material in the gap for dry air, $\Sigma_r = 1$

A = area of plates in (metre)^2

d = gap in metres

Fig. 1: Typical capacitance sensor

If a metal or doped semiconductor is stretched or compressed, its resistance changes because of dimensional changes (length and cross-sectional area) and resistivity change (the latter property is called Piezoresistance). Strain gauge technology is used to measure the change in length from L to)L and resistance change from R to)R. The strain sensitivity or gauge factor (G), can be calculated by ()R/R)/()L/L). For metal strain gauges, the typical gauge factor is 2. These strain-measuring devices are normally called strain gauges and come in different sizes. Fig. 2 shows an outline of a bonded foil strain gauge.

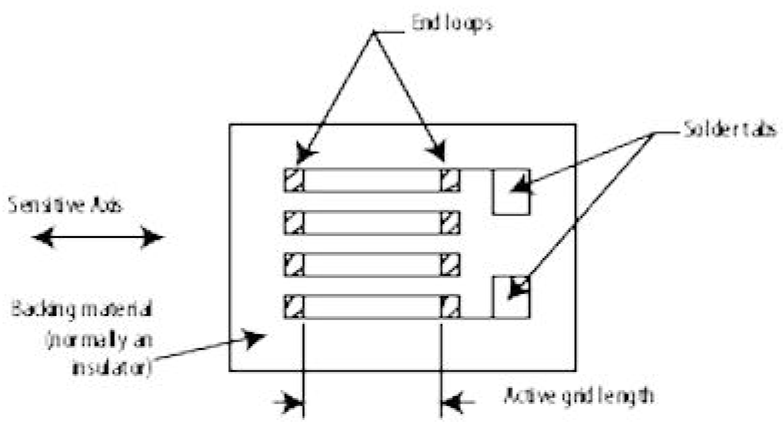


Fig. 2: Typical bonded foil strain gauge

Bonded foil strain gages are made of nickel chromium or nickel constantin material, and typically have a Mylar insulator backing. This allows users to glue the gauge to a metallic or ceramic substrate. Thin-film gauges, fabricated by sputtering metal on an insulated substrate, do not require any glue for bonding. In the early 1960s, semiconductor gauges were developed to offer higher gauge factors (from 55 to 200) with smaller package size. Semiconductor gages can be fabricated in two ways: the use of bulk silicon or germanium material that has been doped in either P-type such as boron or N-type material such as phosphorus to provide the electrical and thermal performances; ion implanting using P and N type types of material together to form a p-n junction.

These strain gages are normally connected in a Wheatstone Bridge configuration as shown in Fig. 3 (depicting four active arms for maximum compensation) to provide a limited temperature compensation. For metal or thinfilm strain gauges, the output signal is 3mV/V with an operating strain of 1,100 micro strain, whereas semiconductor gauges will provide up to 50mV/V with 300 micro strain. ‘Sensor’ed Packaging Primary pressure sensor packaging is dependent on the sensing technology and operating conditions of an application. Signal conditioning electronics and electrical interface can be considered secondary issues for the purpose of this discussion. Let us review some of these packages, benefits and issues.

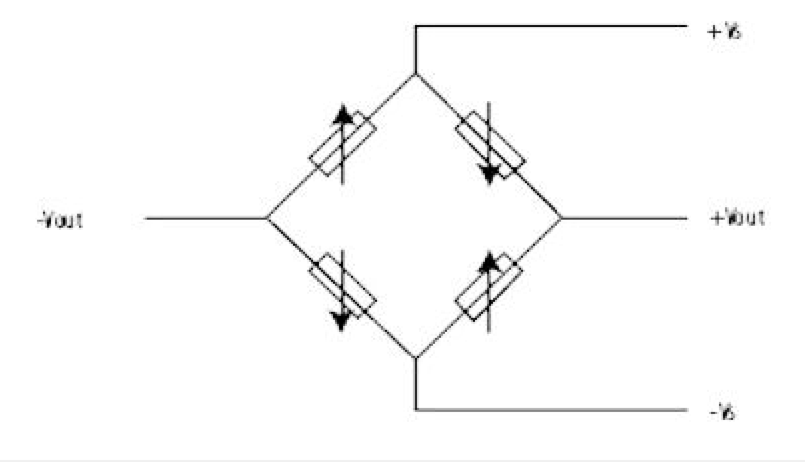


Fig. 3: Wheatstone Bridge Circuit

Most low-cost ceramic capacitive sensing elements employ a ceramic diaphragm made with an Alumina 96 machined pressure port, retainer ring, housing and O-rings. The ceramic diaphragm is normally held to the pressure port by means of a primary O-ring. A secondary O-ring is used with the retaining ring on the opposite side to hold the ceramic diaphragm when pressure is applied. In this design, the media comes in contact with the ceramic diaphragm, primary O-ring and pressure port material. For lowpressure applications, the ceramic diaphragm tends to be large and thin. This has the potential for failure under high shock and vibration conditions.

Ceramic sensors are used in industrial and off-road applications up to 1,500 PSI (100 Bar); however, the proof pressure (also known as the overload pressure) is restricted to 1.2X the rated pressure. Today, this technology has limited use above 1,500 PSI due to the availability of low-cost strain gauge technologies with much better performance and longevity. In cyclic environments, the proof pressure rating must be reduced to the same as operating pressure range to avoid failure of the O-ring seal. Since this design does not incorporate a hermetic seal, these sensors are not suitable for operation in ammonia, hydrogen, oil and gas production, hydraulics, oxygen service, and many other critical mild-to-harsh applications. The O-ring can be specified in a range of materials to deter specific media attacks that can cause system failure in certain abusive environments. Sensor manufacturers typically provide a list of O-ring materials such as Buna, Viton, and EPDM that can be specified by the customer.

Since the metal foil strain gauges tend to be large, they are normally put on a beam or a diaphragm prior to welding to a pressure port. Thin-film sensors are smaller; however, they also need to be welded to a pressure port. In both cases, the welds need to be deep enough so that they do not fail under normal and overload conditions, especially when operating above 2,500 PSI (170 Bar). Under high cyclic and pressure conditions, where the pressure pulsations can vary by 50 percent of the pressure sensor range, the sensor package design must incorporate a mechanism to make sure that the weld is under compression to avoid sensor failure. Since both metal foil and thin-film technologies have low outputs at high operating strains (typically 1,000 microstrain), the diaphragm material must be carefully selected, so there is enough room for over pressure, without sacrificing shift in sensor performance.

Common diaphragm materials used in metal foil and thin-film sensors tend to be 15–5 PH, 17–4 PH and 17–7 PH high-strength stainless steels, with yield strengths up to 190,000 PSI and low thermal coefficient of expansion. The pressure ports must be of the same material as the diaphragm to avoid any separation of the welds under thermal conditions.

Sensors employing semiconductor strain gauge technology can be divided into two categories—oil-filled sensors employing a thin isolation diaphragm and ion implantation technology, and the emerging diffusion bonded bulk silicon Krystal Bond Technology. Oil-filled piezo-resistive sensors mainly employ a small silicon chip with ion implanted strain gauges, isolated from the real world by means of a thin metallic membrane (typical thicknesses between 0.001 and 0.0015” depending upon the pressure range). This design is not suitable for high cyclic environments since the thin welded diaphragm will fatigue and lead to sensor failure. As the pressure and temperature increases, the silicone oil will become compressible, leading to a shift in the sensor calibration and eventual failure due to deformation of diaphragm.

With Bulk Semiconductor Strain Gauge Technology, the strain gauges are directly mounted onto a machined sensing element, where the diaphragm and pressure port are machined in the same process. This eliminates the problems associated with welds, oilfilled cavities and internal Orings. The use of a direct inorganic diffusion process allows semiconductor gauges to be placed precisely on a metallic diaphragm, on the side of the diaphragm that is not exposed to the media. The hermetic design is excellent for high cyclic environments associated with hydraulic pumps and motors. The high gauge factor, along with low operating strain, allows the diaphragm to be thick, offering excellent proof and burst pressures.

Protecting Against Pressure Spikes

Hydraulic systems tend to generate rapid, high-frequency pressure spikes and transients that may last from a few microseconds to hundreds of milliseconds. The rapid opening and closing of valves and solenoids generates these transients. The amplitude of these fast-moving transients can be up to 20 times the rated pressure of a system, and will destroy electronic pressure sensors, unless they are protected using snubbers and restrictors. These protection devices can be installed as an integral part of the sensor or as a standalone device.

Depending upon the design, the devices can dampen the response time of the sensor, while protecting it from damaging fast-moving transients. Fig. 4 shows the details of integral and external pressure spike snubbing techniques. For system optimisation such as response time and snubbing, the length (L) and diameter (D) must be carefully selected. In an ideal condition, the snubber must be able to snub all signals that are between 100 and 150 percent of the applied pressure to maintain fast throughput, but remains dependent upon the type of sensing technology and packaging.

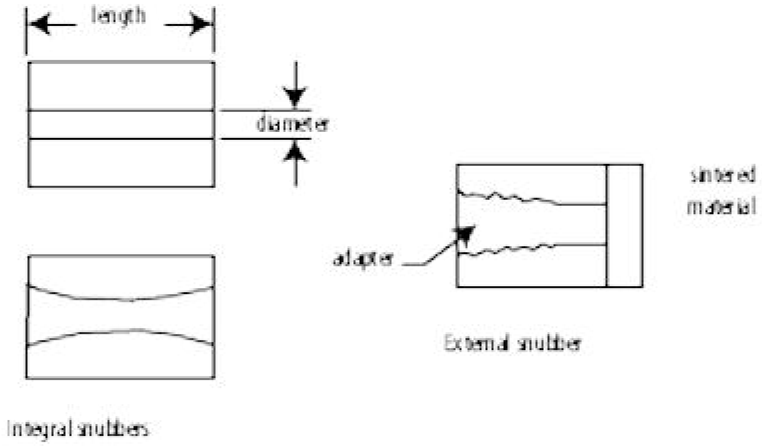


Fig. 4: Snubber design considerations

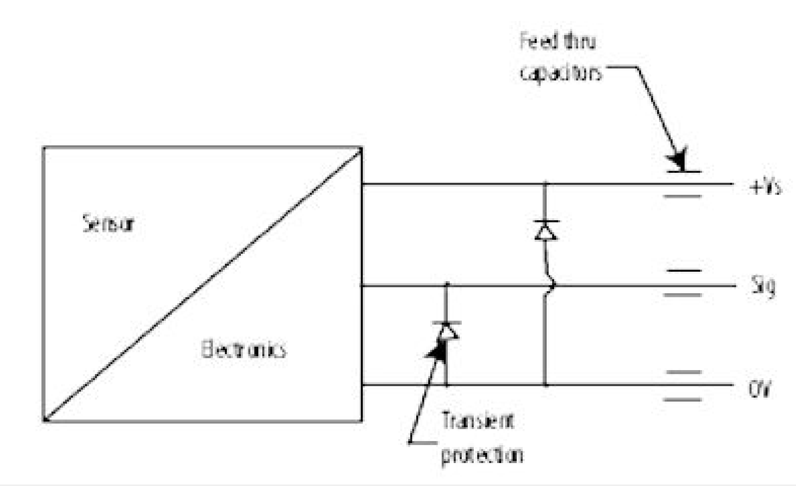


Fig. 5: Typical EMI/RFI Protection

EMI/RFI Protection

In mobile hydraulic applications, electrical pollution in the form of fast electrical transients, Electro Static Discharge (ESD) and EMI/RFI must be contained for system stability. Examples of this interference include communications equipment, switching power supplies, welding equipment and electric motors. The sensor package must not generate or be influenced by unwanted external electrical signals from 100 kHz to 2 GHz. It must also be able to withstand radiated and conducted susceptibility and operate within its published specifications in critical applications such as mobile cranes, scissor jacks, forklifts and many others. Typical protection used can be seen in Fig. 5.