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ABCs of REFRIGERATION PRESSURE SENSING

Sealing techniques figure heavily into what technology makes sense in different portions of the refrigeration cycle.

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Typical refrigeration sensors like this go into many commercial cooling installations.

Supermarket refrigeration systems, rooftop chillers, walk-in fast-food-restaurant freezers, and refrigerated rail cars vary greatly in size and appearance. Yet they all share the same basic principles of refrigeration. In each system, pressure sensors are vital in controlling the refrigeration cycle and keeping the system efficient.

The basic refrigeration cycle is a four-step process. Low-pressure refrigerant vapor enters the compressor where the volume is compressed and temperature rises. The high-temperature compressed refrigerant enters the condenser where excess heat is removed either by blowing cooler air over the refrigerant tubes or circulating water around the tubes. The refrigerant condenses into a liquid phase while maintaining high pressure. The high-pressure liquid refrigerant passes through an expansion valve where it undergoes a rapid reduction in pressure. The refrigerant boils as it converts back to a vapor. The phase change from liquid to vapor produces a large drop in vapor temperature. The cold vapor passes through the evaporator where it absorbs heat from ambient air forced through the evaporator coils by a fan. The chilled air maintains the temperature in a freezer or it can cool a room.

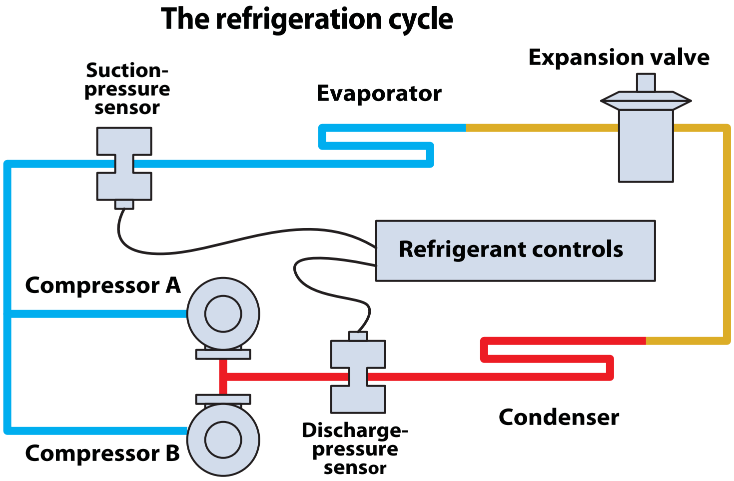
When refrigeration is used to cool a large building, water rather than air is circulated through the evaporator. The water passes through cooling radiators throughout the building that picks up heat. The system is called a chiller. A 2-in. pipe of chilled water can supply as much cooling comfort as a round air duct with a diameter of 42 in.

Evaporators in supermarket systems are the rectangular boxes located inside freezers with fans that blow freezing air. The remaining components are located outside the freezer, many times in a mechanical room or even on the roof. Evaporators in large buildings that use chilled water typically are the big boxes on the roof.

Pressure-sensor use depends on the size of the system and type. As the cooling load grows, the physical size of the compressor grows and energy requirements become significant. A common window air conditioner relies on a temperature sensor to determine when to turn on the compressor and start the cooling cycle. It runs at the requested speed until turned off by the thermostat with the rate of cooling controlled by the speed of the fan blowing air through the evaporator.

These systems use a switch to sense the amount of pressure in the system. Insufficient pressure indicates there has been a refrigerant

Edited by Robert Repas



Low-pressure refrigerant vapor is compressed to raise its pressure and temperature before going through the condenser. The condenser cools the vapor, turning it into a liquid while keeping the high pressure. The liquid refrigerant loses pressure as it passes through the expansion valve, changing from liquid back to vapor with a drop in temperature. The now cool vapor passes through the evaporator where it cools air or water circulating around the evaporator. The warmed vapor returns to the compressor, and the cycle repeats.

leak that may lead to an overheated compressor and possible damage.

Compressors, fans, and defrost operations in refrigeration systems contribute a high percentage of energy use in buildings and supermarkets. Larger units employ complex control systems to optimize performance and reduce energy costs. Pumps and compressors are brought online or shut down in response to the cooling load which varies from day to day and even on the time of day.

Pressure sensors normally reside at two locations in refrigeration systems. The first point is on the output side of the evaporator, which is also the suction side of the compressor. The second is on the discharge side of the compressor. Some systems employ sensors in both locations. Smaller systems may use one or the other. In chillers, there are additional pressure sensors used to control the pumps that distribute chilled water. The most critical location is on the suction side of the compressor. That sensor stages fans and, in conjunction with a temperature sensor and system controller, controls the expansion valve in many systems.

Large supermarket refrigeration systems typically employ multiple series of compressors and evaporators. There may be a low-temperature system for freezers and a medium-temperature system for the milk case. Larger supermarkets can have multiple parallel systems operating at different temperatures and pressures. Other systems have large manifolds on the discharge side of the compressors that maintain pressure at a fixed level. Multiple evaporators handle the different food cases at varying temperatures. As cooling load rises, additional compressors are brought online to maintain manifold pressure. The control system uses pressure sensors as an integral part of that system to control the pressure and thereby superheating and supercooling in the refrigerant loop.

Sensors located on the output side of the evaporator are exposed to very-cold refrigerants. They must perform well in cold temperatures. And because it is possible for ice to build up on these sensors, they must have a robust environmental seal that keeps out moisture. The best sensors for this location are absolute-pressure sensors or sealed gage-pressure sensors (absolute sensors calibrated to simulate a gage sensor). Those sensors do not need an outside air vent to function correctly as do true gage sensors. Though gage sensors employ hydrophobic filters to block water intrusion, they still pass humid air that winds up inside

REFRIGERANT-SENSOR TECHNOLOGIES

	Ceramic capacitive	Piezoresistive	Thin film
Pressure ranges	0-1 to 0-150 bar	0-6 to 0-400 bar	0-25 to 0-1,300 bar
Seal	O-Ring	Weld	Weld
Application	Low and high pressure	Low and high pressure	High pressure
Advantages	Lowest cost; low and high-pressure ranges; best temperature performance; small size	Sealed; low and high-pressure ranges; high-overpressure capability; broader selection of pressure ports, and connectors; 0-to-10-V and 4-to-20-mA outputs available	Highest pressure; low cost; sealed; high-overpressure capability; small size
Disadvantages	Match O-Ring seal material to refrigerant	Cost	Low-pressure limits; stability at lowest temperatures; gage only configurations

This table compares the various approaches, advantages, and disadvantages designers face from sensor technologies used with refrigeration systems.

the sensor. When refrigerant cools the sensor, moisture from the humid air condenses and creates long-term reliability issues. Those who have lived through this type of problem tend to specify these sensors be either absolute or sealed-gage varieties. They generally refuse to consider sensors or technologies that are gage by nature.

Most pressure sensors found in refrigeration systems are built using either ceramic-capacitive, piezoresistive, or thin-film technology.

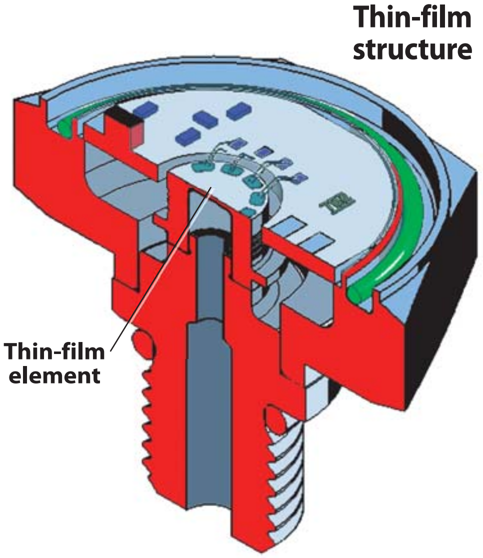
The sensing element in ceramic-capacitive sensors consists of a ceramic body bonded to a thin ceramic diaphragm. Gold is plated and patterned on the two pieces to form two capacitors — a sensing capacitor and a reference capacitor. As pressure is applied to the diaphragm, it deflects and reduces the spacing between the plates of the capacitors, thus boosting capacitance of the sensing capacitor. An application-specific integrated circuit (ASIC) compares the values of the sensing and reference capacitors and converts the difference to a proportional pressure value. The ASIC uses internal algorithms to convert the measurements to a linear, temperature-compensated output. This is a quite inexpensive structure widely used in cost-sensitive refrigerant systems. In addition, capacitance does not change with temperature. The calibration needed for very low temperatures is inherently easier and more accurate than alternate approaches.

A rubber O-ring seals the ceramic sense element to a brass or steel housing. The O-ring material must be compatible with the refrigerant. Though the O-ring seal is tight, supersensitive refrigerant sniffers will smell refrigerant through the O-ring, registering an extremely low-level refrigerant leak. Even such a small amount of leakage eliminates this technology from consideration in some applications. In addition, the refrigerant may contain other materials. For example, there are always traces of compressor oil and possibly small amounts of water and other contaminants that may be incompatible with the O-ring.

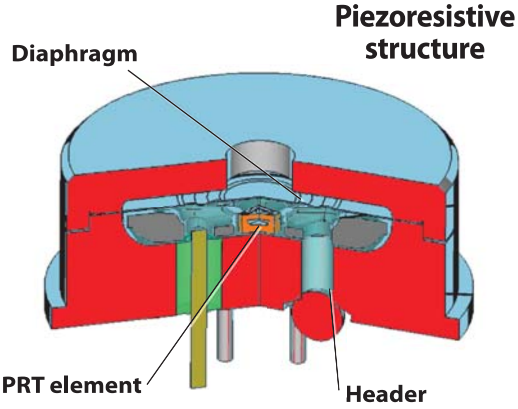
Refrigeration piezoresistive sensors have a piezoresistive pressure-sensor element in a sealed, oil-filled header. The element is a silicon-integrated circuit that contains four resistors arranged in a Wheatstone Bridge configuration. Pressure applied to the diaphragm transmits through the incompressible oil to the silicon sense element inside. Based on the physical layout of the resistors, the pressure puts the bridge out of balance, creating an output voltage from the device with power applied to the element. This output is usually measured in millivolts. An ASIC inside the sensor amplifies and temperature compensates the signal before sending it to the outside world.

This type of structure benefits from a welded construction. All parts exposed to the refrigerant are typically stainless steel. The structure is inherently robust and resists most overpressure spikes. Because it is welded, there is no chance for refrigerant leaks. This type of sensor is found in many industrial products from a wide range of suppliers and comes in many different pressure port, electrical connector, and output configurations. One disadvantage is that the resistive sense elements are inherently more affected by temperature than capacitive elements. Thus great care must go into calibration to compensate for temperature changes. Accuracy and stability of this structure degrade as working pressure drops, limiting the practical low-pressure end of the scale.

Some thin-film sensors operate in a way that resem-



A four-resistor network in a Wheatstone-bridge arrangement is applied to a machined stainless-steel button. The thin steel button bulges under pressure, changing the resistance and unbalancing the bridge, producing an output voltage. An advantage of the thin-film sensor is that stainless steel is the only material touching the refrigerant.



The piezoresistive technology (PRT) element is a silicon-integrated circuit that contains four resistors in a Wheatstone-bridge configuration. Pressure applied to the element changes the resistance and unbalances the bridge to produce an output voltage.

bles piezoresistive structures. The sense element is formed by machining the inside of a stainless-steel button until the remaining steel is quite thin. Exotic materials are deposited on the steel surface forming a Wheatstone-bridge-resistor network. The resistive material differs depending on the manufacturer. The element is typically welded in a stainless-steel front housing. The strain transfers to the resistors as pressure is applied to the back of the element unbalancing the bridge. That imbalance manifests as a small voltage output when the bridge is powered. That voltage must be amplified and temperature compensated to be useful. As the desired pressure range drops, the sense element must become thinner or larger in diameter to boost sensitivity.

This sealed structure presents only steel-wetted surfaces to the refrigerant. The output value of the sensor depends on the materials used to form the resistors. As stated earlier, that material can vary significantly from supplier to supplier. The greater the voltage response to a pressure input, the easier it is to calibrate the sensor and more accurate the ultimate output.

The properties of the film dictate the magnitude and stability of the sense element output. All thin-film sensors are not created equal. Some common materials, like NiCr, have poor temperature stability limiting their use at low temperatures. Practical limits on the low end limits this technology to pressures above 20 bar. In many cases, that restricts its use to sensors located in the high-pressure area of the refrigeration system. However, it's low cost and ability to handle high pressures makes it the technology of choice for CO_2-based refrigerant systems.

All in all, there is no "best choice" sensor for refrigerant system designers. Major factors to consider include the choice of a sealed or O-ring product and whether the costs at anticipated volumes outweigh the flexibility in electrical connectors or output format. Factors that also influence sensor selection include location in the cooling cycle, the refrigerant, and the desired pressure ranges. **MD**

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