the **difference** between

THE DIFFERENCE BETWEEN:

Force Measurement Techniques

Engineers in many industries need reliable ways to measure compressive force, either during product development or as an embedded component within a product or device. In industrial automation, machines must measure and regulate the forces they apply to the objects with which they interact. Medical devices and human-machine-interfaces (HMIs) need to measure force as well, albeit on a much smaller and more precise scale.

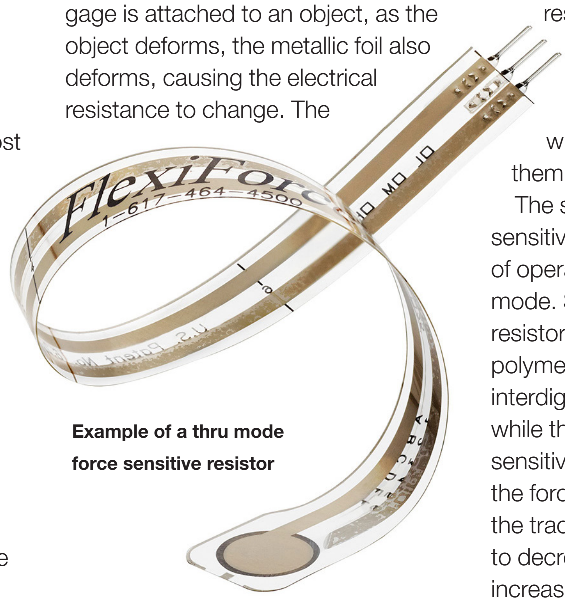
NO MATTER THE APPLICATION, engineers often wonder about the best method for measuring force feedback in their applications. They must take power requirements, form factor, accuracy, upfront and operating costs, and other considerations into account. In a broad sense, load cells and force-sensitive resistors (commonly referred to as FSRs) are the two most common methods. Force sensitive resistors can be further broken down into thru mode and shunt mode categories. Read on to learn about the differences between these force measurement techniques.

Design and Operation

Load cells are transducers that, when connected to appropriate electronics, return a signal proportional to the mechanical force applied to the system. They can be hydraulic, pneumatic, or—most commonly—based on strain gages. The most common types of strain gages are sensors made from an insulating base material with a metallic foil mounted to it. When the strain gage is attached to an object, as the object deforms, the metallic foil also deforms, causing the electrical resistance to change. The resistance change is related to the strain by the strain gage's gage factor.

Strain gage load cells typically use a single- or double-ended beam setup and between one and four strain gages. The beam is either fixed on one end and loaded on the free end, or else fixed on both ends and loaded in the center. In either configuration, loading deforms the metal beam and produces a slight strain in the gages bonded to the beam surface. The strain produces a very small change in the electrical resistance of the gages which associated electronics typically translate to a millivolt signal. Greater loads cause greater strain and a proportional increase in the resulting signal.

Another way to provide embedded force feedback is with force sensitive resistors. While strain gages are planar resistors that change resistance in response to surface deformation, force sensitive resistors change resistance when force is applied directly to them.

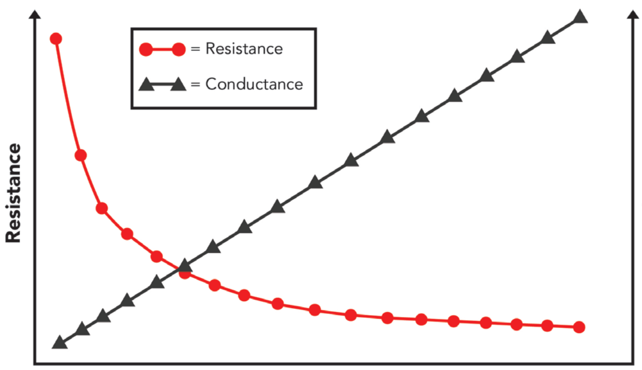


Example of a thru mode force sensitive resistor

The specific design of a force sensitive resistor depends on its mode of operation: shunt mode or thru mode. Shunt-mode force sensitive resistors consist of two thick-film polymer layers. One layer contains interdigitated conductive traces while the other is comprised of force sensitive material. As force is applied, the force sensitive material shorts out the traces, causing the resistance to decrease as the applied force increases.

Thru-mode force sensitive resistors also consist of two layers, both thin-film polymers with traces. Each polymer layer contains a semi-conductive pressure sensitive element printed on a conductor. The two layers are adhered together. In the unloaded condition, the sensor's resistance is very high (typically MΩ). As force is applied, the pressure sensitive elements within the sensor contact each other and elastically deform. As more force is applied, the resistance of the sensor decreases (typically kΩ). Inversely, the conductance of the sensor increases as applied force increases. The relationship between conductance and applied force for a thru-mode sensor is linear. This will be described in more detail in the next section.

Force VS Resistance & Force VS Conductance of Common Touch Sensor Technology



This graph shows the effect of force applied to a thru mode sensor. With greater applied force, the sensor's resistance decreases and generates a linear conductance signal.

Performance

For an engineer seeking force feedback from an application, of equal or greater importance than how it works is how well it works. For that reason, measures of accuracy and precision, linearity, and dynamic range are of vital importance.

Load cells are well known for their high accuracy, which had led them to become staples in test-and-measurement applications. Well-calibrated load cells are accurate to within 0.1% or less of their full scale.

Force sensitive resistors are good at relative measurements—that is, detecting incremental changes in load such as those needed for force feedback in medical and human-machine interface applications. They are less accurate in absolute measurement, with well-calibrated shunt-mode force sensitive resistors running average errors in the range of 4 to 6% of absolute, and thru-mode force sensitive resistors coming in around 5 to 10% of absolute (depending on the quality of the calibration).

Linearity describes how closely a force measurement sensor's output conforms to a straight line drawn between maximum and minimum loads or other calibration points. A sensor with low linearity error, usually expressed as a percentage of full scale, is much simpler to calibrate. Engineers can trust that the readings between calibration points are accurate and that the slope of the sensor's conductance curve is constant through its designated force range. The benefit of this is that fewer intermediate calibration points are needed.

The design of the force sensor can affect its linearity at different loads. For example, load cells exhibit nonlinearity at the lower end of their load range. This makes them better suited for higher loads, but also diminishes their useful range. Engineers using load cells should make sure to limit surplus load capability and protect the load cells from temporary overloading while being sure to keep loads above the lowest calibration point.

Thru-mode resistors are linear from 0N to the top of their range and exhibit nonlinearities of ±3% of full scale throughout. Shunt-mode force sensitive resistors have a tendency to deviate from linear behavior even within their designated force range. Users of shunt-mode force sensitive resistors will need to use more calibration points than they would with thru-mode sensors.

The range of measurable loads is another consideration for force measurement techniques. Most engineers are more interested in dynamic range, which is the likely range of force values the sensor will see in its application. Load cells can be designed for a wide variety of dynamic ranges, with the lower end detecting loads of 0.5N or less and the upper end reaching into the tens of thousands of Newtons.

Force sensitive resistors, in contrast, are designed to accurately measure smaller amounts of force. Shunt-mode force sensitive resistors are designed for forces

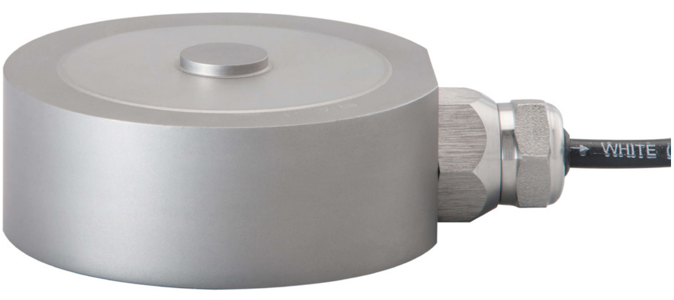


Image courtesy of Flintec

between 0.2 and 20N. Thru-mode force sensitive resistors can be customized to measure and maintain linearity through a variety of dynamic ranges between 0.002 Pa and 69 MPa (10,000psi).

Some force sensors can drift over time so that the electrical signal is returned by the sensor changes despite a constant load. Drift can be exacerbated by environmental effects like changes in temperature or humidity. Load cells, for instance, can drift when temperature changes cause expansion or contraction of the surface to which the strain gages are mounted, especially if they are not arranged in a self-correcting Wheatstone bridge configuration.

For shunt-mode force sensitive resistors, the standard drift is 5%/log(time). Thru-mode force sensitive resistors are rated <5%/log time. In both shunt and thru-mode force sensitive resistors, drift rates can vary based on material interface.

Electronics and Maintenance

One aspect of choosing the right force measurement sensor for an application is considering the infrastructure that goes along with that sensor. Each sensor type requires integration into a measurement circuit so that an analog signal proportional to applied force can be generated. There are also power requirements and maintenance to consider.

The power and signal processing requirements vary with the type of force measurement sensor. Load cells require a conditioned power source that supplies the voltage expected by the sensor, usually 10VDC or less. They also need a dedicated digital signal processing (DSP) setup which enables extremely precise force measurement, but adds complexity and cost to the setup and makes it harder to integrate into a streamlined application.

Both shunt-mode and thru-mode force sensitive resistors have a simple relationship between conductance (1/Resistance) and force. This makes determining force from the sensor output more straightforward. And because they are more often used for relative force measurements, no special provisions need to be made for supplying power. Force sensitive resistors can typically be powered through a simple op-amp circuit or a voltage divider. Depending on the application, the force measurement range and resolution of the force sensitive resistors can be adjusted by changing drive voltage and the resistance of the feedback resistor.

Anyone who has used a load cell knows that maintaining calibration is paramount. Load cells are calibrated with great precision by the manufacturer and may need to be sent off for recalibration periodically, or after adverse events like shock loading or overheating. Force sensitive resistors are calibrated by the user, which can be convenient, but also introduces the possibility of user error.

Design Considerations

A major factor in the choice of a force measurement sensor is how well it will fit into your design or lab setup. Form factors and sizes play a major role in how easy it is to integrate the sensor into a product. Cost and maintenance are other factors in the integration decision.

Load cells usually have a three-dimensional, fixed shape and tend to be bulky. Designers working to integrate load cells into a product usually need to build parts of the design around the sensor, making it hard to quickly iterate the design. Load cells' power and DSP requirements and their higher cost have made load cells a challenge to integrate into today's streamlined designs.

Both thru-mode and shunt-mode force sensitive resistors, on the other hand, are flat and flexible. Along with the fact that they can be powered via simple electronics, force sensitive resistors are much easier to integrate into machines, robotics, and human-machine interfaces. Force sensitive resistors are also lower in cost and require less infrastructure, so designers can more easily play around with how best to integrate them into a design. ■