Sensors Online
September 2004

SENSOR TECHNOLOGY AND DESIGN

Electrolytic Tilt Sensors and Inclinometers:

A Primer

Electrolytic tilt sensors and their instrumented cousins, the inclinometers, can tell you whether and by how much something is leaning referenced to gravity.

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The term *tilt sensor* is often used to identify a large variety of devices that measure, indicate, or otherwise provide a signal of some type when tilted from (or to) a level position, using gravity as a reference. While a number of these devices are indeed tilt sensors, others are not. To determine what actually qualifies as a true tilt sensor, we must first understand what, exactly, one is.

A tilt sensor can be defined as a device that produces an electrical output which varies with angular movement. This definition excludes all visual/mechanical devices such as "ball-in-tube" slope indicators, pendulum protractors, and bubble levels, as well as devices that use mercury switches and/or electromechanical triggers that deliver strictly ON/OFF-type outputs.

Within the sensor industry, *tilt sensor* generally refers strictly to the sensing element itself, devoid of any I/O conditioning electronics. Once conditioning electronics are added, the enhanced device becomes known as an inclinometer (or clinometer). Although both the sensing element and the clinometer have an electrical output that varies with angular movement, this nomenclature is widely accepted.

Types of Tilt Sensors and Inclinometers

Many types of tilt sensors and inclinometers are available on the market today, some of them dating back more than 50 years. Most can be assigned to one of three categories: force balanced, solid state (MEMS), and fluid filled. Each category encompasses many variations, each having its own advantages and disadvantages. For example, the force-balanced type generally provides superior performance but costs more. MEMS-based designs feature integral signal conditioning and relative ease of installation, but their extremely high thermal coefficients require significant compensation to obtain acceptable accuracy in many applications. Fluid-filled tilt sensors constitute the largest industrial market sector by far, due primarily to their relative low cost-to-performance ratio. This genre consists primarily of electrolytic- and capacitance-based technologies. While these sensors are limited in terms of response time, most applications are effectively static, so this is not a problem.

Electrolytic Tilt Sensors

The most enduring of all tilt sensors to date is the electrolytic type. Spectron Glass and Electronics effectively pioneered this industry, developing many of the first electrolytic tilt sensors to hit the market. The original design and operating principles are still valid, and continue to be widely used today. This technology is unique in lending itself to both narrow and wide angular range measurements, while maintaining compact size and high accuracy. The other fluid-filled types are comparatively bulky, and cannot achieve high accuracy over shallow angular ranges.

Operation

Figure 1 depicts a single-axis tilt sensor. An electrically conductive fluid (electrolyte) is sealed in a glass or ceramic cavity to conduct between a common, a positive, and a negative electrode. When at electrical null (i.e., level), both electrodes are evenly submerged in the fluid, which remains level due to gravity. This produces a balanced (equal) signal output between the positive and negative electrodes and the common.

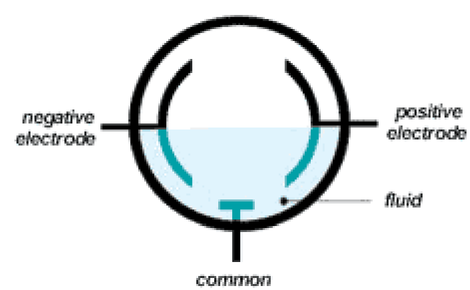

Figure 1. When both the positive and negative electrodes are equally submerged in the fluid (electrolyte), the tilt sensor is at its null (zero) output position. The sensor's nonlinearity is typically best about this position, and it is where users should attempt to center their normal angular measurement range to optimize performance.

As the sensor is rotated about its sensitive axis, the amount of submerged surface area will increase for one electrode, and simultaneously decrease for the other, thereby creating an imbalance in the output (see Figure 2). This imbalance, or ratio, of one electrode to the other is directly proportional to the angle of rotation.

The sensor shown in Figures 1 and 2 has a relatively simple "open-cavity" design that would have a total sensing range of approximately ±70º. All fluid-filled types are limited to a total sensing range of less than ±90º because the electrodes become either totally retracted or submerged in the fluid when approaching that angle. Once this occurs, the sensor is in what is known as overrange, or saturation, and no variation in the output will be observed. This limitation can be overcome by incorporating a second tilt sensor offset 90º (in the sensitive axis) to the first. Doing so provides a full 360º sensing range, but requires a sophisticated multiplexing routine within the electronics to discern the correct angular position.

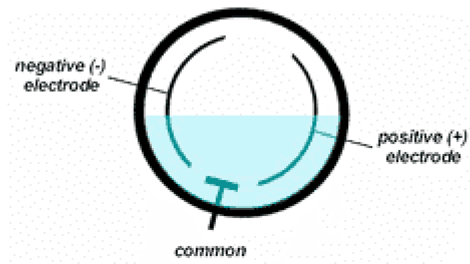

Figure 2. An output is generated when the sensor is tilted away from the null position and the submerged portions of the electrodes are no longer balanced. The signal conditioning electronics will in turn convert this imbalance into a usable signal.

Angle measurements below ±15º require a significant increase in the radius of the fluid cavity. Electrode alignment within the cavity also becomes extremely critical. The designs shown in Figure 3 feature sub-arc-second resolution. Furthermore, altering the profile of the internal cavity serves to attentuate the device's sensitivity to vibration, a typical problem with fluid-filled sensors.

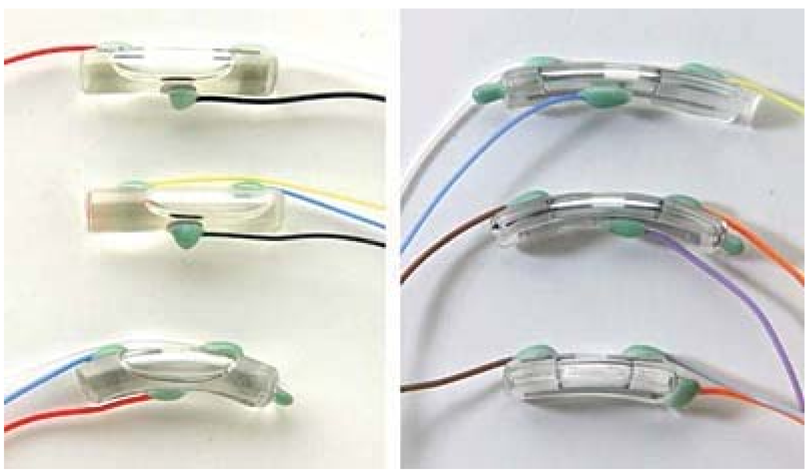
Figure 3. These glass tilt sensors were designed specifically for highly linear, shallow angular range measurements of ±0.25º to ±12º. The RG Series (left) is the most accurate, and is intended for more static applications. The CG Series (right) has a specially designed fluid cavity that minimizes the effects of vibration on null shift (4.2 g_{rms} 5–150 Hz, 3.0 g_{rms} 150–500 Hz).

Dual-axis (X and Y) tilt sensing calls for two sets of electrodes, one positioned perpendicular (orthogonal) to the other. Spectron's dual-axis tilt sensor platform consists of a cylindrical glass envelope and five pins that act as the common, positive, and negative electrodes for both axes (see Figure 4).

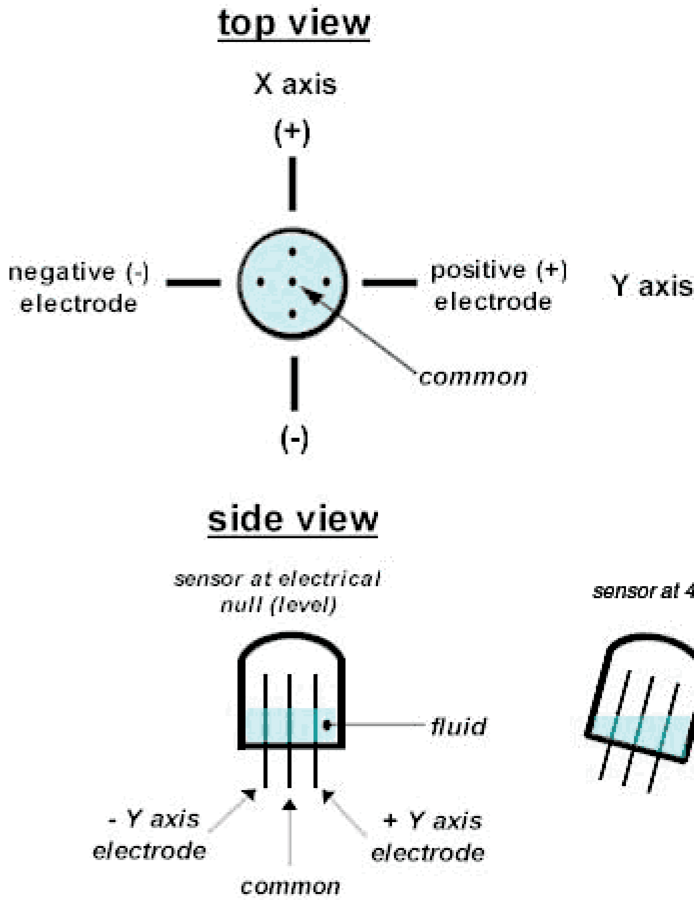

Figure 4. This is a typical design configuration for a dual-axis tilt sensor. The four plus and minus sensing electrodes (2 per axis) are positioned symmetrically around the center/ common electrode. Positional errors of the electrodes, as well as other variable factors, affect linearity performance and must be minimized during manufacture.

Sensor Conditioning

Tilt sensors are typically interfaced with signal conditioning circuits as a voltage divider or ratiometer (see Figure 5).

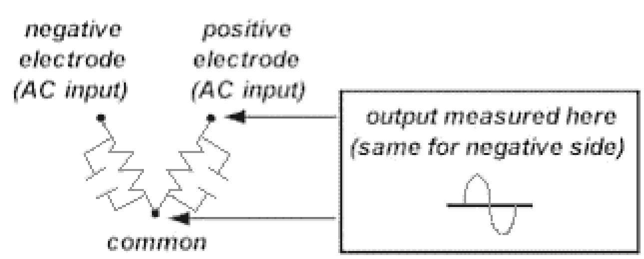

Figure 5. Electrolytic tilt sensors are AC-operated devices with both resistive and capacitive components. The most common treatment of the sensor within a conditioning circuit is as one half of a Wheatstone bridge, and provides intrinsic/desirable performance effects.

The advantages of this configuration include normalizing of both minor changes in the excitation voltage and temperature effects. The most popular electrical circuit configuration is the AC Wheatstone bridge. The sensor can be used as a half bridge with the full excitation voltage across the sensor, or as the lower half of the bridge, with resistors in series with each half of the sensor.

At null, the sensor produces a signal equal to 50% of the total scale factor (output) setting. Angular motion in either direction increases or decreases this ratio proportionately. For dual-axis operation, a duplicate signal conditioning circuit is required for the second axis.

Inclinometers

As noted above, inclinometers (see Figure 6) combine a tilt sensor with integral signal conditioning electronics. Mechanical mounting features of some type are usually incorporated to provide a positive reference surface that is used to align the inclinometer during installation. Many users prefer inclinometers to tilt sensors as a way to sidestep the laborious tasks of circuit design, sensor mounting and alignment, and calibration.

Figure 6. The Spectrotilt electronic inclinometer has a ±60º total range, allowing use in widely varied applications. Onboard linearity and temperature error correction enable absolute measurement accuracies as high as ±0.3º. The mounting features and package size are industry standard.

As are tilt sensors, inclinometers are available in both single- and dual-axis configurations. Dual-axis designs (see Figure 7) may incorporate a single dual-axis tilt sensor or two single-axis sensors. The latter is sometimes required, as single-axis sensors are generally more accurate.

Applications


Figure 7. The Spectrotilt II dual-axis inclinometer uses a single dual-axis sensor (center). A matching-hole pattern for the sensor electrodes (pins) is incorporated into the circuit board. Soldering the sensor to the circuit board provides both the electrical and mechanical connection.

Electrolytic tilt sensors and inclinometers are typically used either when something needs to remain level or when the out-of-level condition (angle) must be determined. Applications in the construction industry range from safety systems for cranes, manlifts, and telehandlers, to providing level reference data for various types of lasers. The automotive industry uses tilt sensors and inclinometers in wheel alignment machines for measuring caster and camber angle and for RV leveling systems. Avionics manufacturers have for decades used high-precision tilt sensors in gyroscopes, and more recently in electronic standby instrument systems for initial alignment. Other applications include satellite antenna positioning, geotechnical monitoring (e.g., soil subsidence, structural and dam monitoring), and tilt compensation in electronic compasses.

Looking Ahead The performance and reliability of electrolytic tilt sensors and inclinometers continue to set the standard for fluid-filled devices. Future developments will focus on improving dynamic performance and increasing total range. Improvements are also in the works for design, materials, and manufacturing techniques. Finally, the recent availability of reasonably priced microprocessors has made digital linearity and temperature compensation affordable, even in lower cost devices.