

傾斜センサ及び傾斜計(電解液式) 入門

(Electrolytic Tilt Sensors and Inclinometers A Primer)

傾斜センサとは何か? (What Is A Tilt Sensor?)

The phrase 'tilt sensor' is a term, which has been widely used, and misused over the years. It is frequently employed in a generic fashion to describe a large variety of devices, which either 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, the others fall into various categories, which by their very definition negate their inclusion. However, to make a distinction as to what actually qualifies a device as a true tilt sensor, we must first understand what one is.

A tilt sensor can be defined as a device, which produces an electrical output that varies with angular movement. Though brief and rudimentary, this definition plainly makes two pertinent points: the device must have an electrical output, and that the electrical output must vary when tilted. With this understanding, all visual/mechanical devices such as ball-in-tube style slope indicators, pendulum protractors and bubble levels for that matter, are automatically eliminated. Also eliminated are devices, which use mercury switches and/or electro-mechanical triggers that strictly deliver on-off type outputs.

Within the sensor industry, the term tilt sensor becomes a bit finer. Normally it will refer strictly to the sensing element itself, devoid of any input/output conditioning electronics. Once conditioning electronics are added, the aggregate device then becomes known as an inclinometer. Although both have an electrical output, which varies with angular movement, this distinction is commonly recognized.

傾斜センサと傾斜計のタイプ (Types Of Tilt Sensors And Inclinometers)

There are many types of tilt sensors and inclinometers available on the market today, some whose history extends back more than 50 years. There are three major categories, which encompass the majority of types available. They are force balanced, solid state (MEMS) and fluid filled. Within each category there are many variations, each having their own advantages and disadvantages. For example, the force balanced variety generally provides superior performance, but comes at a substantially higher cost. The MEMS based devices feature integral signal conditioning and relative ease of installation. However, thermal coefficients are extremely high, and significant compensation is normally required to obtain acceptable accuracy in most applications.

The fluid filled variety of tilt sensors comprises the largest industrial market sector by far. This is primarily due to the relative low cost to performance ratio. Within this genre we find primarily electrolytic and capacitive technologies. While limited in terms of response time, the majority of applications are effectively static, rendering this attribute moot.

傾斜センサ(電解液式) (Electrolytic Tilt Sensors)

The most enduring of all tilt sensors to date is the electrolytic type. Pre-dating World War II, this sensor's roots extend back to the Genesis of electronic tilt sensing. Spectron Glass and Electronics, who effectively pioneered this industry, developed many of the electrolytic tilt sensors to first hit the marketplace. The basic design and operating principles originally employed are still valid, and continue to be widely used today. This technology is unique in the fact that it lends itself to both narrow and wide angular range measurements, while maintaining compact size and high accuracy. This capability has enabled servicing of a diverse range of markets. Comparatively, the other fluid filled technologies available are bulky, and cannot achieve high accuracy over shallow angular ranges.

動作 (Operation)

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

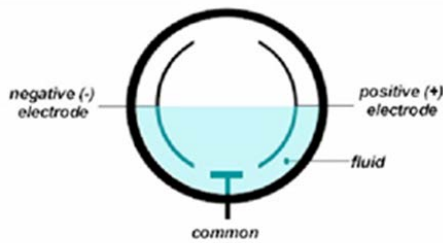


figure 1 - sensor at electrical null, electrodes equally submerged in fluid

As the sensor is rotated about its sensitive axis, the amount of surface area submerged within the fluid 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.

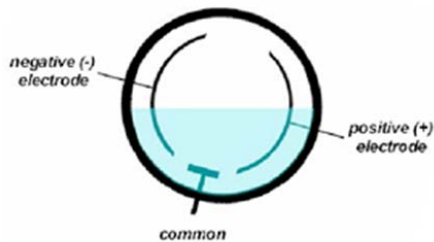


figure 2 - sensor at +15 degrees, positive electrode submerged further than negative electrode into fluid

The illustrations above depict a relatively simple open-cavity design, which would have a total sensing range of approximately +/- 70 degrees. All fluid filled type tilt sensors are limited to a total sensing range of less than +/-90 degrees, as the electrodes will become either totally retracted or submerged when approaching that angle. Once this occurs, the sensor is in what is known as over-range or saturation, and no variation in the output will be observed. This limitation can be overcome with an approach, which incorporates a second tilt sensor offset 90 degrees (in the sensitive axis) to the first. This design successfully provides a full 360 degree sensing range, but requires a sophisticated multiplexing routine within the electronics to discern the correct angular position.

For narrow angle range measurements of below +/-15 degrees, the geometry of the sensor changes dramatically. To maintain acceptable accuracy and sensitivity, the radius of the fluid cavity must greatly increase (see figure 3). Electrode alignment within the cavity also becomes extremely critical. This highly developed design produces the most accurate tilt sensors available on the market, with sub-arc second resolution. Furthermore, by altering the profile of the internal cavity, excellent results have been achieved in attenuating sensitivity to vibration, a typical problem with fluid filled devices.

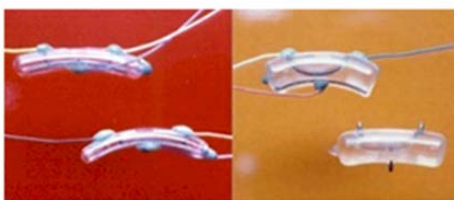


figure 3 - Spectron CG and RG model Electrolytic Tilt Sensors have a total sensing range of +/-0.25 to +/-12 degrees.

2 軸傾斜センサ (Dual Axis Tilt Sensors)

When dual axis (X and Y) tilt sensing is required, two sets of electrodes are required. The second set of electrodes must be accurately positioned, perpendicular (orthogonal) to the first set. Spectron has developed a dual axis tilt sensor platform, which is comprised of a cylindrical glass envelope, and five (5) pins which act as the common, positive and negative electrodes for both axis (see figure 4).

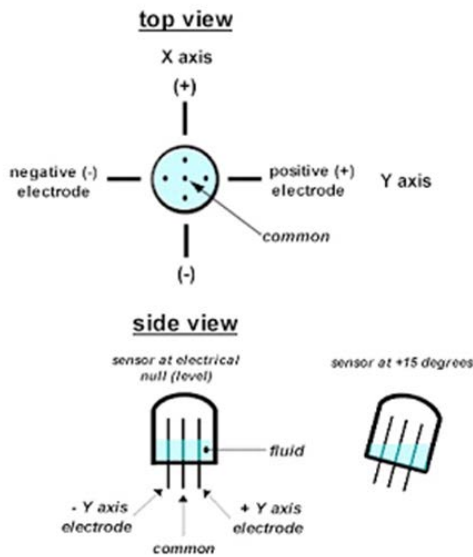
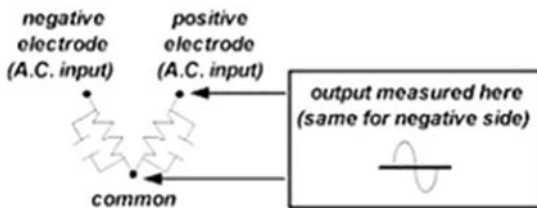


figure 4 - Dual axis tilt sensor outline

傾斜センサのコンディショニング (Tilt Sensor Conditioning)

The traditional interface of the tilt sensor into a signal conditioning circuit is as a voltage divider or ratiometer. This provides intrinsic advantages such as the normalizing of minor changes in the excitation voltage and temperature effects.



Equivalent Sensor Circuit

The most popular electrical circuit configuration is the A.C. Wheatstone bridge. The sensor can be used as one half the 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 (i.e. zero or level), the sensor will produce a signal equal to 50% of the total scale factor (output) setting. With angular movement in either direction, this ratio will increase or decrease proportionally. For dual axis operation, a duplicate signal conditioning circuit is required for the second axis.

傾斜計 (Inclinometers)



The Spectrotilt Electronic Inclinometer from Spectron features a variety of electrical interface options, fully potted electronics, EMI and ESD protection, and absolute accuracies as high as ± 0.3 degrees.

As previously explained, an inclinometer combines a tilt sensor with integral signal conditioning electronics. Normally, mechanical mounting features of some type are incorporated, which provide a positive reference surface. This surface is used to properly align the inclinometer during installation. Many users prefer inclinometers to tilt sensors, as it eliminates the laborious tasks of circuit design, sensor mounting/alignment and calibration.

Same as tilt sensors, inclinometers are available in both single and dual axis configurations. Dual axis inclinometers may utilize a single dual axis tilt sensor, or two single axis sensors. The latter is sometimes required, as the single axis tilt sensors generally have higher accuracy.



The Spectrotilt II Dual Axis Electronic Inclinometer from Spectron, shown using an SP Series electrolytic tilt sensor.

アプリケーション (Applications)

The applications for electrolytic tilt sensors and inclinometers are extremely diverse, touching most industries in some way. In general, they are enlisted when something either needs to remain level, or when the out of level condition (i.e. angle) needs to be determined.

Within the construction industry the applications 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 security and RV leveling systems. Avionics manufacturers have used high precision tilt sensors for decades in gyroscopes, and more recently in electronic standby instrument systems for initial alignment. Other notable applications are satellite antenna position, geotechnical monitoring (soil subsidence, structural and dam monitoring), and tilt compensation in electronic compasses.

展望 (Outlook)

The future appears bright for both electrolytic tilt sensors and inclinometers. The performance and reliability of electrolytic tilt sensors continues to set the standard for fluid filled devices. Planned improvements in design, materials and manufacturing techniques promise to raise the bar even higher.

The more recent availability of reasonably priced microprocessors (PICs) has made digital linearity and temperature compensation affordable. The result has been the realization of accuracy levels once thought unachievable in lower cost inclinometers, facilitating entry into new markets. Forthcoming developments will focus on improving dynamic performance and increasing total range, thereby further widening the available market



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