High accuracy Electronic Inclinometer replaces the common *water level*

For hundreds of years, the 'water level' has been a mainstay of the toolbox. Commonly known as a 'spirit level' or 'bubble level', this simple but clever device was designed to indicate whether a surface is horizontal (level) or vertical (plumb). Many variations of spirit levels continue to be used today by carpenters, stonemasons, bricklayers, building trades workers, surveyors, millwrights and other metalworkers, and in some photographic or videographic work.

More recently, advances in sensing technologies, and the affordability of micro-electronics, have opened the way for replacement of these devices with more accurate electronic substitutes.

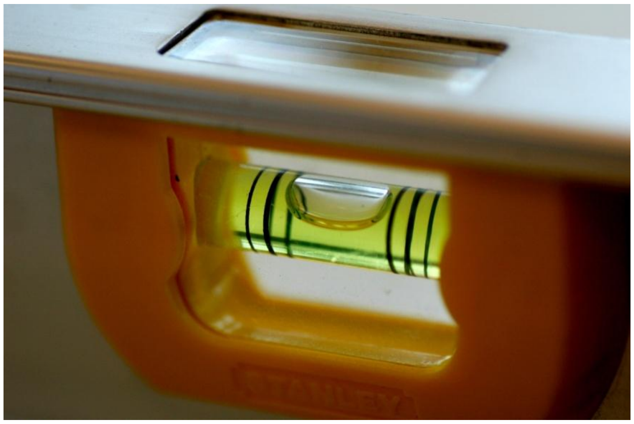

Fig. 1: **Conventional water level**

The conductometric measuring principle

A water level operates on the principle that water will seek its own level (i.e. 'planar orientation'), due to the effects of gravity. In practical use, it simultaneously measures and displays the orientation of an object with respect to the direction of gravity, defining the horizontal plane. This traditional method of measurement, though still widely used, does have a number of shortcomings. Most notable is the uncertainty of the angle indication due to parallax, a variable error related to the observers' line of sight. Second is that it requires human intervention, immediately eliminating it from all embedded installations and remote monitoring applications.

To create a high accuracy, electronic equivalent of the water level, a method of converting a liquids reaction and position relative to gravity, and to electrical stimulus would be required. The liquid would also have to possess electrically measurable attributes, and be readily available. All these elements can be found in electrolytic liquids. Electrolytic liquids are chemical compounds which dissociate to ions in the presence of an electrical field. By submerging two planar electrodes with opposite polarization into the liquid, this effect can be utilized to achieve an angular measurement. The electrodes deliver an electric current, whose amplitude varies depending on the voltage, as well as the number and the valence of the ions. The phenomenon is described as electrolytic conductibility χ (conductibility = 1/electric resistance), and is expressed as the measuring unit Siemens $S = \Omega^{-1}$.

The basic operating principle of an "electronic water level" therefore connects the electrical conductibility of the liquid (local quantity of ions) to the orientation of the recipient, with respect to a tilting axis.

A clinometer based on this methodology contains two pairs of electrodes, mounted in the base of a recipient containing the electrolyte, parallel to the tilting axis. In order to eliminate polarization effects on the electrode surfaces, an alternating voltage is applied, generating a stray field on either side (see *fig. 2*). A reduction of the filling height decreases the number of ions above the electrode, as well as the conductibility, and the filling height itself is determined by the tilting angle. This means that the change of the tilting angle (i.e. the inclination with respect to the horizontal plane) gives rise to a change of the electric conductance.

This is the basic principle of the conductometric measuring method.

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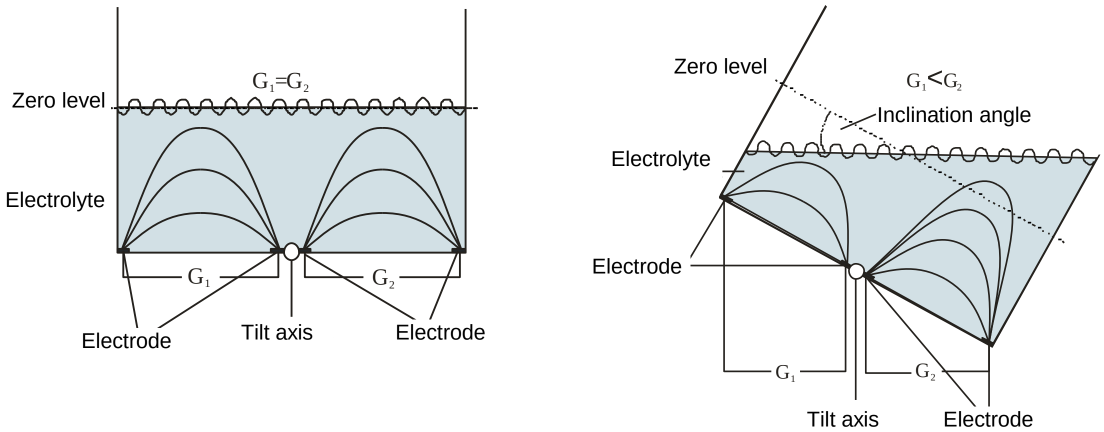

Fig. 2: Measuring the tilting angle by means of the electric conductance

In order to determine the direction of tilt ($G_1 \leq G_2$ or $G_2 \leq G_1$), the alternating voltage of the electrodes is applied in anti-phase. A fifth electrode is provided (measuring electrode), detecting the superposition of the electric fields. When at null (i.e. level), both fields are equal (except for the phase), and the resultant signal output is zero (compensation of the interference), since the fields are compensating each other.

When tilted around the central axis, fluid will flow more into one side of the recipient, as it seeks level (see illustration above). The pair of electrodes submersed in a higher quantity of fluid will produce a higher output signal, and vice versa. This imbalance is detected by the measuring electrode. When tilting the system into the opposite direction, the signal correspondingly changes sign. This is the basic construction of a single-axis clinometer, designed to measure positive and negative tilt angles. A dual-axis clinometer contains a duplicate set of electrodes aligned with the orthogonal axis and is capable of measuring tilt angles in both the XY planes simultaneously.

This patented method has been combined with sophisticated signal conditioning electronics, enabling development of high precision electronic clinometers, as described in the following section.

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Description of the conductometric DPL series

The conductometric measuring principle has many advantageous features. They are as follows:

- Stable origin
- Reliable long-term stability
- High resolution
- Very low temperature drift.

This method is the core of our DPL series (see *fig. 3*).

The DPL Series Inclinometers are dual-axis tilt sensors with measuring ranges of ±2°, ±5°, ±10°, ±15° and ±30°. Active temperature compensation and a linearized output signal are provided by a high speed microprocessor, allowing for an angular resolution of 0,001° and an accuracy of 0.08° maximum, within the operating temperature range of 0°C to +50°C. The offset value of ±0.08° and the offset drift of 0.05° (between 0°C and +50°) make this inclinometer an ideal choice for clinometric applications with an angular range of up to ±30°.

The sensors are positioned in the X and Y (orthogonal) axes, and are securely mounted to a 45 x 45mm printed circuit board.

Fig. 3: **Dual-axis inclinometer, DPL series**

The DPL Series delivers a UART (TTL - Level) or SPI digital output signal, and is programmable (baud rate, data speed, origin, single point detection). An adjustable filter enables for suppression of external shock and vibration signals.

The large number of user selectable parameters allows for specific configurations in a multitude of industrial and mobile applications.

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Examples for application of single- and double axis sensors:

- **Weighing systems** (Mobile charge weighing e.g. for tank trucks (*See fig.* 4)
- **Construction engines** (Mobile and stationary cranes, other devices for road and channel construction)
- **Joy-ride protection in cars**
- **Charging supervision** (chassis supervision, evacuation of tilting silos)
- **Supervision of buildings and bridges** (general dynamics, earthquake protection, supervision of deformation)
- **Platform leveling** (measuring and working tables, medical applications, movable platforms, drilling installations, forest vehicles and fire engines)
- **Regulation of the brake pressure** (heavy load vehicles)
- **Inclination control** (ships and airplanes)
- **Positioning** (photovoltaic installations, observation stations e.g. telescopes, radar plants, laser systems, optical measuring systems)

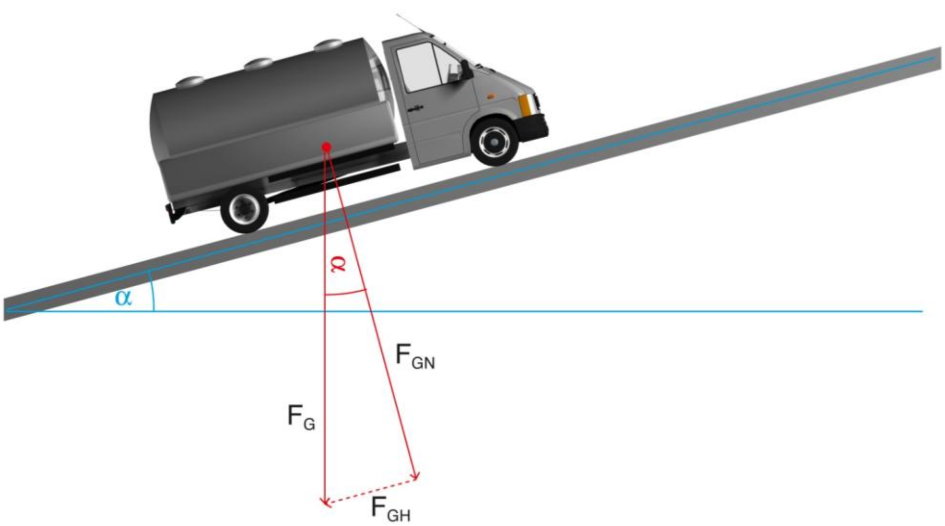

***Fig. 4*: Determination of the angle of inclination enables an electronic parking brake adjustment, in order to optimize the braking pressure to current conditions (useful particularly for commercial or farm vehicles)**

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Adaptation of the brake pressure depending on the inclination angle

The inclinometer detects the vehicles angle of inclination α with respect to level (0°). The admissible weight of the vehicle amounts to F_G = m x g (m = mass of the vehicle, and g = gravity).

The required brake force (hand brake) must be sufficient to withstand any external influence (wind, attempts to displace the car mechanically, suction of passing cars, etc.). Whenever the vehicle is parked at a slope (α >0°) however, an additional force must be taken into consideration, which varies depending on the weight of the vehicle, and on the exact angle of inclination. According to *fig. 4*, the mass of the car F_G is subdivided into two components: F_{GN} (acting perpendicularly to the road = normal component, and F_{GH} (descending force).

The latter one is the factor which has to be added to the original value, to prevent the vehicle from rolling down.

This factor calculates to $F_{GH} = F_G \times \sin\alpha$.

So that the vehicle could be parked on a hillside it must be offered a power e.g. brake power, which compensate the downhill-slope forces, according to this the brake power must be $\geq F_{GH} = F_G \times \sin\alpha$.

The accurate determination of the angle of inclination therefore allows for convenient adjustment of the brake pressure to current conditions, which is required particularly for electronic brakes.

Conclusion

The conductometric measuring principle is based on simple fluid dynamics principles. This, coupled with the properties of electrolytic liquids, and the connection between the fluid level height and the electric field, enables a tilt angle to be electronically converted into accurate measurement information. The integrated microprocessor based electronics allows for linearization of the output signal, as well as correction of temperature effects. Produced by a German manufacturer, MEAS Deutschland GmbH, these high precision inclinometers offers a valuable solution for numerous applications. Numerous input/output configurations are available, in both single and dual axis configurations.

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