Geo Tech Note:

Using Tilt to Measure Displacement

(reprinted from Measurement & Control Magazine, September 1993)

In my 15 years in the sensor business, I have often been surprised by some of the uses and abuses of linear displacement transducers. In particular, some people go to great lengths to make a displacement transducer do a tilt sensor's job.

Reasons for a bias toward displacement measurement are easily understood. Measurement of linear distance is taught early in school and performed in our daily lives using rulers, tape measures, etc. Study of angles and rotations typically begins in high school or college. For most people, measuring angles is an infrequent task.

Recent advances have made tilt-sensors the choice for many linear-displacement measurement jobs. Tilt sensors include *gravity-referenced* and *locally-referenced* devices. Locally-referenced devices (e.g. rotary potentiometers, optical encoders) measure the angular position of a shaft with respect to its housing. Gravity-referenced devices use the vertical gravity vector as the unchanging reference state. The most versatile of the latter category are liquid-filled sensors containing a trapped bubble. Angular position is sensed either resistively or capacitively between sets of internal electrodes or capacitor plates.

Gravity-referenced tilt sensors have the following advantages:

1. They can be installed anywhere and will always maintain their stable reference.
2. They are small; many bubble-types are less than 0.3 in^3 in size.
3. Liquid-filled sensors have no mechanical moving parts and don't wear out.
4. They are sensitive. Submicroradian sensitivity and dynamic range exceeding 100 dB are routine.

The following examples show how tilt measurements are sometimes the easiest route to finding linear displacements.

Maintaining Parallel Planes

Parallelism between two working surfaces or planes is an important requirement in many industrial processes. These include certain lapping and grinding operations, and the use of coordinate measuring machines (CMMs). Measuring separations with LVDTs is commonly tried and then discarded because of accuracy and mechanical interference problems. However, a small tilt sensor attached to each plane can ensure that rotations (θ) of one are matched by rotations of the other. As long as there is no differential rotation between planes, parallelism is maintained (Figure 1).

Measuring Tank Level

Measuring the elevation (level) of liquid in a tank is a common task easily accomplished with a tilt sensor. Figure 2 shows a tank with a ladder or beam of length L to which the tilt sensor can be attached. The ladder rolls across a floating roof by means of a wheel as its bottom end. If no roof is present, the wheel is replaced by a float. Liquid level h with respect to the tank top is given by the equation $h = L \sin \theta$.

Measuring Beam Deflection

Last year I attended a conference in which a leading bridge engineer spoke about measuring the deflection of the loaded deck of an old bridge. The speaker's approach was to place numerous vertically-oriented LVDTs on the tops of specially built platforms. The platforms elevated the LVDTs from the ground to the underside of the deck. Foundation problems and LVDT range limits required frequent adjustments. Many man-days and dollars were lost as a result of this approach.

A far simpler method would have been to attach one or more tilt sensors beneath the deck. The rotation θ caused by load application reveals vertical deflection by the formula $h = L \sin \theta$ (Figure 3). If beam curvature is important, the beam is divided into a series of shorter segments and this formula is applied to each segment.

These examples show the versatility of tilt measurements. *M & C* readers will undoubtedly think of many more.

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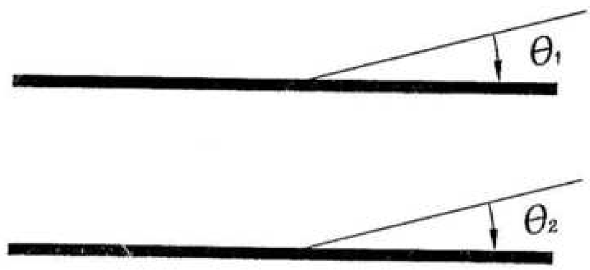

FIGURE 1. $\theta_1 = \theta_2$ = parallel surfaces.

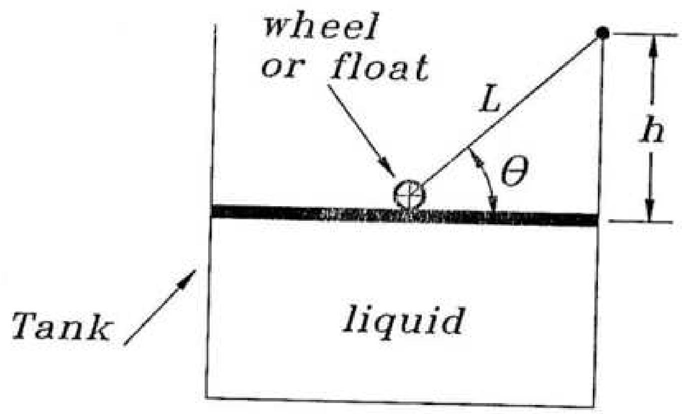

FIGURE 2. $h = L \sin\theta$

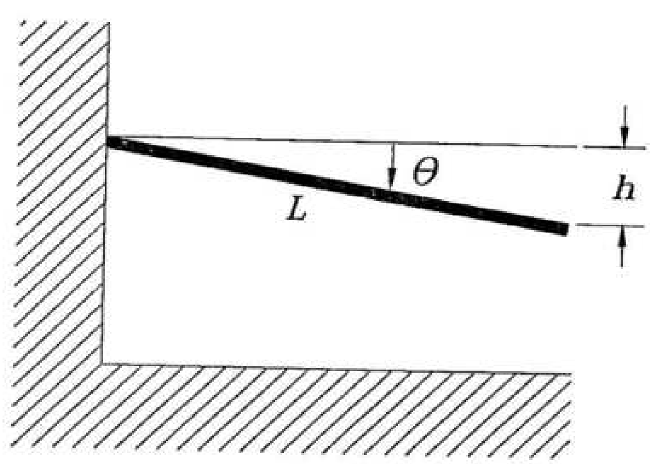

FIGURE 3. $h = L \sin\theta$

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