Why Level Measurement?

Smarter measurement supports more efficient, safer and more sustainable operations, extending the service life and enhancing uptime, whatever the industry sector. The significance of level measurement cannot be overstated whether for Industrial Process Measurement and Control or in Inventory Tank Gauging. In a dynamic system, the Level measurement becomes challenging with the process tanks/vessels which constantly undergoes modifications in the behavior of the measured process fluid due to mixing, chemical reaction, agitation or emptied out for downstream processes based on the application requirements. In such applications, these processes integrated with the fact that these occur at high temperature and/or high pressure pose a safety risk for the personnel and equipment, which makes the Level Measurement even more critical. Any inadequate and improper control can cause levels in the tanks or vessels to be excessively lower or higher than their safe operating limits resulting in damage to equipment, causing overflow or affecting the quality of the final product and potentially developing environmental and safety hazards resulting in financial losses.

In Liquid Level Measurement, it is possible to divide instruments into two basic categories: Point level and Continuous level sensors.

What are Point Level Instruments?

Point level instruments refer to those senses of variation in liquid levels based on the presence or absence of liquid media at different points in a tank or vessel. Point Level Instruments are capable of detecting either Dual pint, Multi-point or single point. Most often, the function of point level sensors are low level or high level alarms, pump protection alarms, spill-prevention sensors or as pump control components.

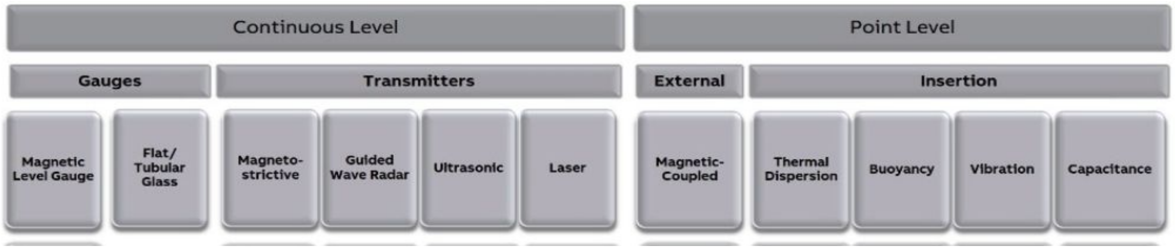
Following are the most common Point Level Technology used in the Industry:

- Buoyancy
- RF Capacitance
- Vibrating Fork
- Magnetic Coupled
- Thermal Dispersion

What are Continuous Level Instruments?

Continuous level instruments are those that transmit the accurate level of a tank/vessel continuously, over the full span of measurement. This is most frequently used for process control via a level absolute precision and accuracy is of extreme importance. Following are the most common Continuous Level Technology used in the Industry:

- Laser
- Ultrasonic
- Magnetostrictive
- Guided Wave Radar
- Magnetic Level Gage
- Differential Pressure



1. **Optical Level Switches**

Pros – Compact, no moving parts, high pressure and temperature capability, can detect tiny amounts of liquids

Cons – Invasive as the sensor requires contact with the liquid, requires power, certain thick substances can cause coating on the prism.

Applications – tank level measurement and leak detection applications.

There are a range of technical terms used to describe this type of level sensing technology. Optical prism, electro-optic, single-point optical, optical level switch…the list goes on. For this purpose, we will use the term Optical Level Switch. The switch operates very simply. Inside the sensor housing is an LED and a phototransistor. When the sensor tip is in air, the infrared light inside the sensor tip is reflected back to the detector. When in liquid, the infrared liquid is refracted out of the sensor tip, causing less energy to reach the detector. Being a solid-state device, these compact switches are ideal for a vast range of point level sensing applications, especially when reliability is essential. Optical liquid level switches are suitable for high, low or intermediate level detection in practically any tank, large or small. They are also suitable for detecting leaks preventing costly damage. Reflected light, such as in a small reflective tank, mirrored tanks, bubbles, milk or coating fluids can often cause issues with delayed readings.

2. Capacitance

Pros – Solid-state, can be non-invasive, compact, accurate

Cons – May require calibration, can only be used in certain liquids

Applications – Tank level monitoring in chemical, food, water treatment, power and brewery industries.

Capacitance level sensors operate in the way that process fluids have dielectric constants, significantly different to air. They measure the change in capacitance between two plates produced by changes in level. Two versions are available, one for fluids with high dielectric constants and one with low dielectric constants.

Capacitance level sensors work with a range of solids, liquids, and mixed materials. They are also available in contact and non-contact configurations meaning some of which can be attached outside the container/tank. When selecting a device, it is important to know that not every capacitance senor works with every type of material or tank. In addition, the sensor needs to be calibrated to the specific material to excuse the varying dielectric constants and differences in the tank design. As this type of technology is contact based, the reliability of these sensors can be heavily influenced by fluids sticking to the probe.

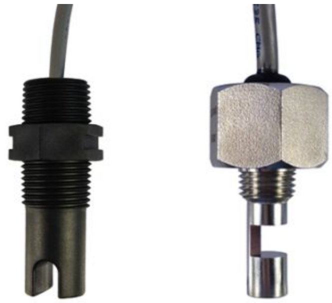
3. **Ultrasonic**

Pros – No moving parts, compact, reliable, not affected by media properties

Cons – expensive, invasive, performance can be affected by various elements in the environment

Applications – Non contact applications with highly viscous and bulk solids. Used in systems that require remote monitoring

Ultrasonic sensors measure levels by calculating the duration and strength of high frequency sound waves that are reflected off the surface of the liquid and back to the sensor – the time taken is relative to the distance between the sensor and the liquid. The length of time in which the sensor takes to react is affected by various elements in the atmosphere above the media such as turbulence, foam, temperature etc. Hence why the mounting position is critical in these devices.



4. Microwave/ Radar

Pros – very accurate, no calibration required, multiple output options

Cons – expensive, can be affected by the environment, limited detection range

Applications – Moist, vaporous and dusty environments. They are also used in systems in which temperatures vary

In principle radar works in a similar way to ultrasonic, but the pulses travel at the speed of light and again; the reliability and repeatability can be affected – but this time by the dielectric constant of the fluid. However, radar can provide very precise level information and also compensate for fixed structures within the container. The downside can be that the initial cost of the sensor is relatively high, but several manufacturers are making this technology more accessible to the wider market. These sensors are among the handful of technologies that work well in foam and sticky substances.

5. **Vibrating or Tuning Fork**

Pros – Compact, cost effective

Cons – Invasive, number of uses are limited

Applications – level control of liquid, powders and fine grained solids within mining, chemical processing and food and beverage industries.

The vibrating sensor technology is perfect for solid and liquid level control, including sticky materials and foam, as well as powders and fine grained solids. However, the types of applications that can use tuning forks is limited to overfill or run dry type applications and they do not provide continuous process measurement. However can be used in conjunction with continuous level detection systems, acting as alarm points for over-filling and leaks.

6. Conductivity or Resistance

Pros – No moving parts, easy to use, low-cost

Cons – Invasive, liquids need to be conductive, probe erosion

Applications – Tank level measurement for boiler water, reagent monitoring, highly corrosive liquids

Conductive sensors are used for point-level sensing conductive liquids such as water and highly corrosive liquids. Simply put, two metallic probes of different lengths (one long, one short) insert into a tank. The long probe transmits a low voltage, the second shorter probe is cut so the tip is at the switching point. When the probes are in liquid, the current flows across both probes to activate the switch. One of the benefits to these devices is that they are safe due to their low voltages and currents. They are also easy to use and install but regular maintenance checks must be carried out to ensure there is no build up on the probe otherwise it will not perform properly.

7. **Float Switch**

Pros: Non-powered, direct indication, relatively inexpensive, various outputs

Cons: Invasive, moving parts, large in size, large amount of liquid has to be present before the float makes contact.

Applications: Tank level applications where water, oil, hydraulic fluids and chemicals are being used.

Float switches are one of the most cost effective but also well proven technologies for liquid level sensing. A float switch includes a magnet within a float and a magnetic reed switch contained within a secure housing. The float moves with the change in liquid and will cause the reed switch to either open or close depending on if it’s in air or liquid. Although simple in design, this technology offers long-term reliability at an attractive price point.

Depending on what mounting style the user chooses heavily depends on the design and construction of the tank or container the switch will be situated. Typically, suppliers will offer a range of mounting options, with the most common being horizontal/side mounting and vertical mounting.

AIM: To make an inductive based level sensor for LN2 level measurement in a tank.

APPARATUS REQUIRED: LCR meter, copper wire, Dewar, Liquid nitrogen, labview for interfacing, heater, superconductors, vacuum pump, He gas, gas balloon, rod.

THEORY:

Inductance based level sensors with superconductor as the core can be used to sense the level of a liquid nitrogen in a cylinder. The principle of this inductive level measurement is based on the drastic change in the inductance of an inductor coil with a superconductor in its core when the critical temperature of superconductor is crossed. The boiling point of liquid nitrogen is around 78K. Hence any superconductor material with critical temperature around this value will serve the purpose.

The inductor coil with superconductor core shows a drastic change in the inductance value when the core goes from normal to superconducting state. Inductance of a coil can be linked with the net change in the flux associated with the coil. When the superconductor is in normal state, the magnetic field linked with current carrying coil penetrates through the core and induces inductance is the coil. But as the temperature is lowered and the critical temperature of the superconductor is crossed, the core becomes a superconductor, it portrays perfect diamagnetism, and hence the flux linked with coil changes greatly, hence the inductance of the coil changes. It is lowered greatly.

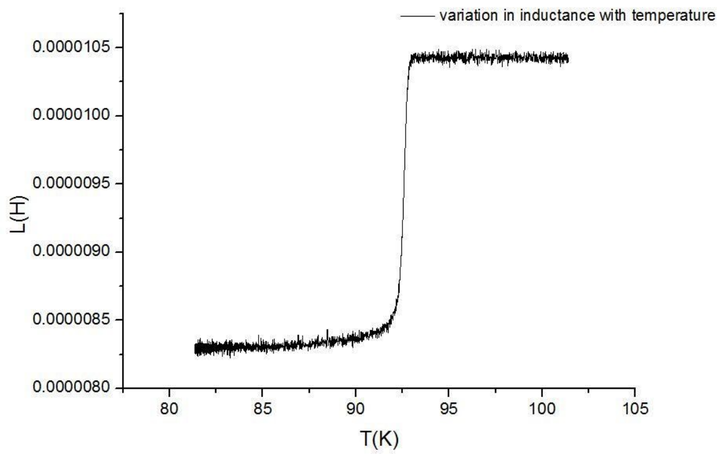


Figure 1: Variation of L with T for an inductor with superconducting core(T_c = 93K)

$\Phi = LI = BA = \mu nIA$

Where,

Φ is the flux linked with the coil
L is inductance
I is the current through the coil
B is the magnetic field linked with the coil
A is the area of the coil
n is number of turns per unit length of the wire
μ is the permeability of the coil

PROCEDURE AND OBSERVATIONS:

A.

1. The inductor was made by winding approx. 50 turns of very thin super enameled copper wire around the superconductor single crystal. The superconductor used is YBCO single crystal. Around six such inductors were made.

Figure 2: YBCO single crystal

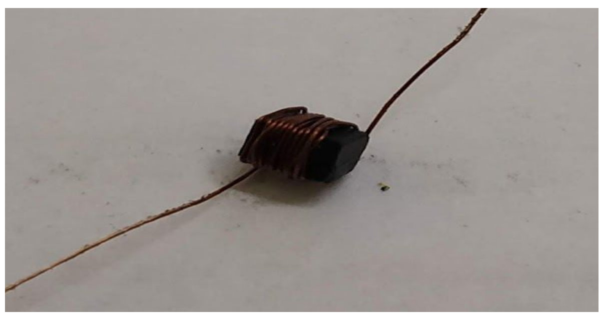


Figure 3: Inductor made by winding copper wire around the crystal

2. Measurements for change in L with temperature were taken using the LCR meter interfaced with labview. The following graph was obtained for a one of the inductor at different frequencies.

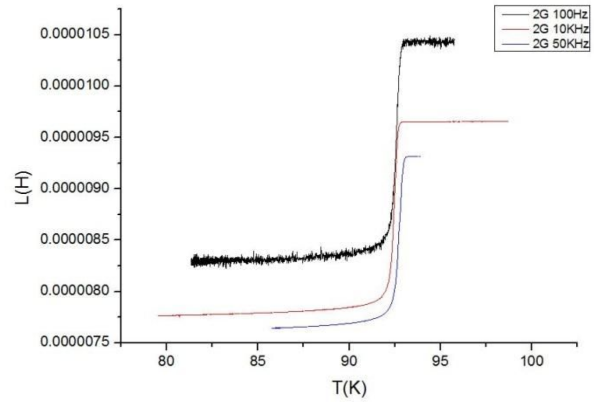


Figure 4: L v/s T for a single inductor at different frequencies.

Since the smoothest transition was observed at 10 KHz, the frequency of 10 KHz was chosen for the operation of the sensor. L v/s T measurements were made for other inductors as well and a small variation of approx 1- 2K in T_c was observed. This can be attributed to the variations in the crystal structure of the superconductor crystal introduced during its making.

3. Next two and three of the inductors were connected in series and L v/s T measurements were taken for them at f= 10 KHz. Following graphs were obtained.

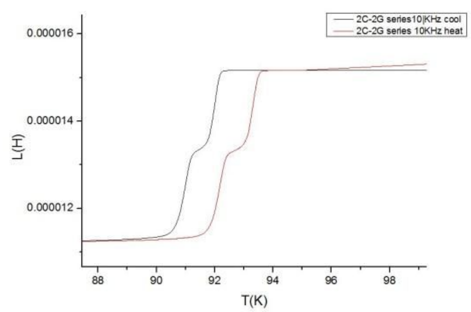


Figure 5: L v/s T for two inductors in series

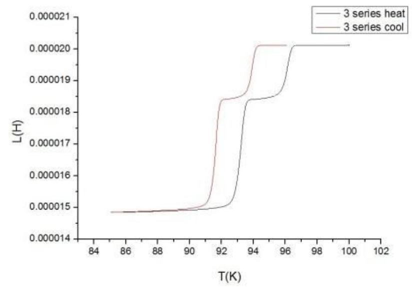


Figure 6: L v/s T for three inductors in series

Transition in L can be seen to be happening in two steps for two or three in series, which can be attributed to slight difference in their T_c.

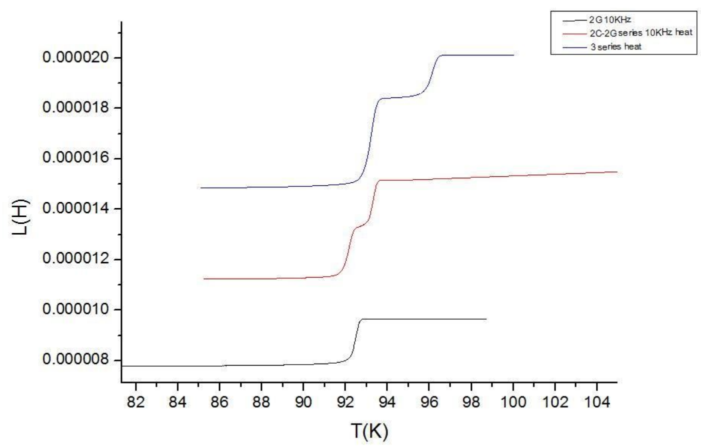


Figure 7: comparison of change in inductance for different number of inductors in series

B.

LEVEL SENSOR FOR DEWAR CONTAINING LN2

1. Five inductors were connected in a series and placed 5 cms apart on a plastic tube.
2. The tube was placed in a dewar containing LN2.
3. Inductors in series were connected to LCR meter and readings were taken for change in net L with time as LN2 evaporated naturally overnight.

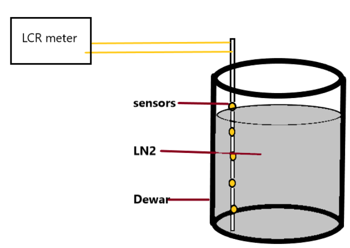


Figure 8: Set up for the sensor.

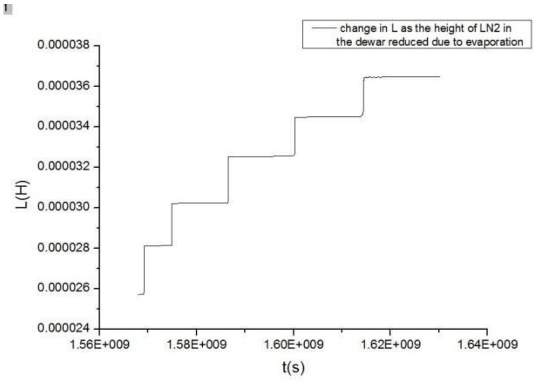


Figure 9: change in Level of LN2 indicated by the change in net inductance.

The response time had been observed to be around 10 sec. For practical applications, inductance measurement can be made using Maxwell's bridge or some IC.

C.

The YBCO crystal has its critical temperature around 92K. To make the sensor more sensitive to LN2 level measurement, a material with T_c around 80K can be made.
From literature survey, it was found that partly replacing the Ba in YBCO with Sr can achieve T_c = 80K.

Preparation of $Y_2BaSrCu_3O_{7-\alpha}$:

The samples were prepared by mixing powders of Y_2O_3, CuO, $BaCO_3$, and $SrC0_3$ in appropriate ratios to produce 3 g samples. The powders were ground with a mortar and pestel, pressed into 0.5 in. pellets, reacted in flowing 0_2 at 950 °C for 24 h, and air cooled to room temperature. The samples were then tested for the Meissner effect, reannealed at 700° C for 24 h in flowing 0_2, and furnace cooled to room temperature (approximately 6 h to 200° C).

These samples were then cut into small rectangular pieces and made into inductors as done for the YBCO single crystal. They were connected in series and placed on a plastic rod and were used to make measurement for the level of LN2 in Dewar as mentioned above for YBCO cored inductors.

RESULT:
It was observed that the Inductance drastically changed as the level of LN2 in the dewar changed beyond a particular height. Though there are other contributors like the plastic rod partly conducts, water gets condensed into ice, etc, the major contribution to the change in inductance was due to the change in superconducting state of the core. For practical application, the winding can be made more uniform and other changes can be made.

PRECAUTIONS:
1. Wires must be connected properly.
2. Heater and LCR meter connections must be checked properly before taking measurements.

3. Liquid Nitrogen should be handled carefully.