Liquid metal level measurement techniques

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Abstract. Various types of liquid metal level measurement are used in various applications. Liquid metals have excellent electrical properties which can also be utilized for level measurement. Many types of level measurement exist such as pressure transducers, floats, inductive devices, resistance tubes, visual etc. Many liquid metals have corrosive or toxic nature. This mandates indirect or non-intrusive means of measurement. So techniques are being experimented even now for the easy attainment of accurate measurements. This paper gives a brief description on various level measurement techniques used to measure the level of liquid metals. Detailed description about a mutual inductance based level probe is also presented in this paper.

1. Introduction

The Liquid level measurement is important in various industrial processes. Different techniques are used to satisfy the requirements of level measurement. Direct and indirect methods of measurement can be used. Level measurement can be in a continuous interval or at discrete points [1-5]. The continuous level measurement provides the exact level of liquid present in certain location. In case of discrete or point level measurement a reference point is given and measurement indicates whether the liquid is above or below the particular reference point [5-10]. Many parameters affect the measurement of liquid metal level liquid metal. Some of these parameters are temperature, pressure, density, corrosive nature, electrical and acoustic properties etc. Normally the level measurement can be done visually by using metre scales [11-15]. The points will be marked in the scale and by placing this in the container the quantity of liquid present is identified. Many a times the liquid metals are stored in closed vessels where visual measurement is not possible [15-20]. Another method consists of placement of a sensor inside the container and producing signal when the liquid comes in contact with the sensor. Each sensor will have different principles and according to this the measurement is done [21-25]. Pressure at the bottom of a container is directly related to the height of the liquid at a constant temperature and thus by measuring static pressure also, the liquid level in a tank or container can be measured [26-30]. The level measurement for liquid metal is challenging because most of the liquid metals have high melting point which requires use of special materials to fabricate sensors [31-35].

2. Methods of level measurement

For non-corrosive liquids like water, level can be measured simply by observing the level of the liquid through naked eyes or we can just insert a scale and measure the level. But this method is not very accurate because of errors in measurement due to manual errors.

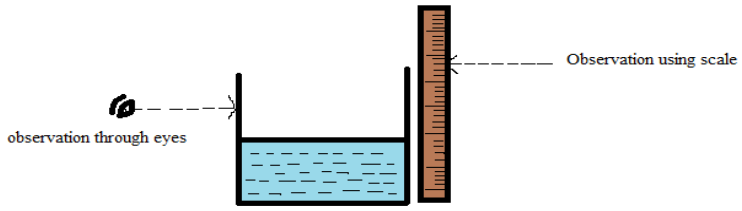

Figure 1: schematic of visual level measurement.

2.1 Direct and indirect methods of level measurement.

Generally there are two types of level measurement i.e. the direct method and the indirect method. In the direct method of level measurement, the varying level of the liquid is used as a means for obtaining the measurement. This is also the simplest method of measuring the liquid level. The level indicators used here are sight glass, Float type and Hook-type level indicator. The sight glass continuously indicates the liquid level within the tank or a vessel. But here the accuracy depends upon the cleanliness of the fluid and the glass. In the float type, a float will be present on the surface of the liquid and as the level changes the float indicates the variation.

2.1.1 Hook-type level measurement. In the hook-type of level indicator, the hook is pushed below the liquid surface and gradually is raised until the point is just about to break through the surface of the liquid. The reading is very accurate. In the indirect methods the level is measured in terms of variables which changes according to the change in the liquid level.

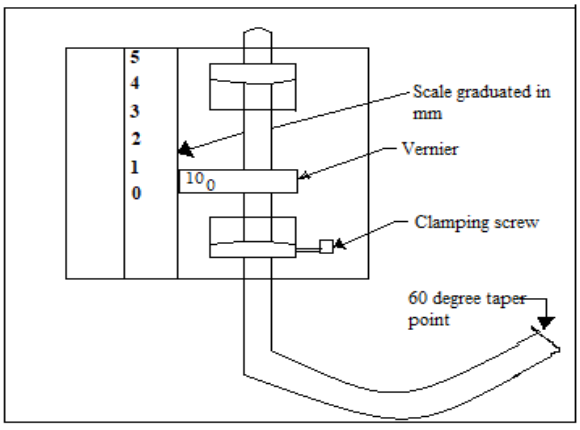

Figure 2: Hook-type level measurement.

The indirect method is based on Hydrostatic head (pressure transmitter), Electrical capacitance method and Radiation method.

2.1.2 *Pressure transmitter for level measurement.* The pressure transmitter can be used to measure the liquid level inside a tank, in the river and other body of liquid. The liquid level can be easily measured through this way. The static pressure at the bottom of a liquid is proportional to the height of the liquid. A transmitter can also be used to measure and record the hydrostatic pressure and thus liquid level can be measured and recorded. The pressure transmitter gives a signal which indicates the level of the liquid. The disadvantage of this method is that, there will be temperature variations and thus the liquid density changes. Thus temperature corrections are required.

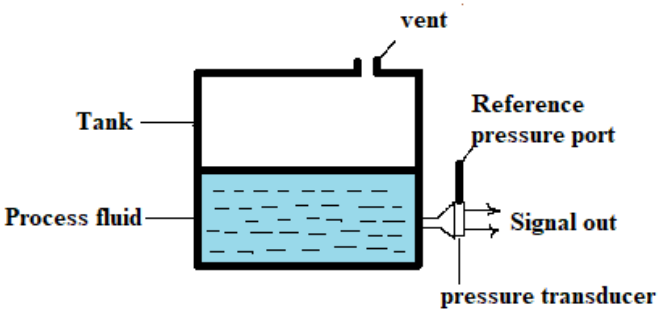

Figure 3: Level measurement using pressure transmitter.

2.1.3 *Electrical capacitance method.* The device consist of an insulated capacitance probe firmly attached parallel to the metal wall of the container. The liquid is non-inductive. Here the probe and the wall acts as two parallel plates and liquid act as dielectric. If we use a conductive liquid, the probe and the liquid acts as capacitance plates and insulation acts as dielectric. The capacitance value is calibrated in terms of level and the measurement can be performed. When the liquid inside the container increases, the capacitance value increases. Selection of correct electrode is important. This is temperature sensitive. The capacitance level indicators find applications in measurement of granular solid levels.

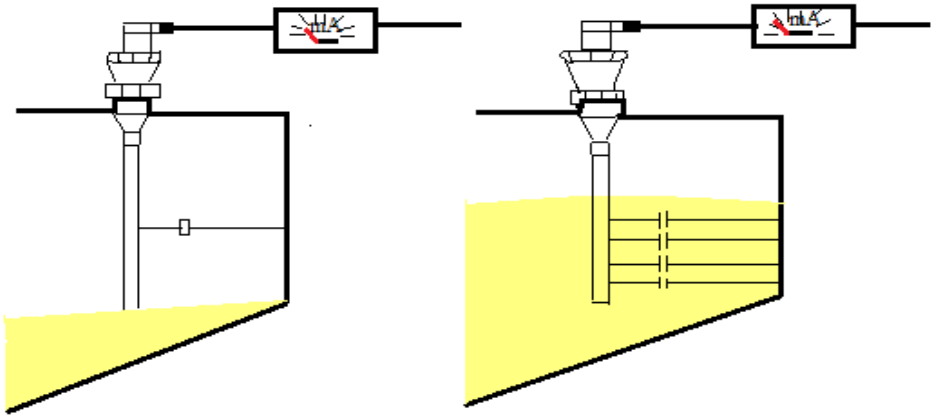

Figure 4: Electrical capacitance method.

2.1.4 *Radiation method of level measurement.* A gamma rays source and a detector is present on either side of the tank whose level is to be measured. This is a non-contact method. A thin layer of gamma ray is released and this will penetrate to the tank and loses its intensity. At the detector end, the reception is inversely proportional to the tank wall thickness and the intermediate medium. The amount of radiation received is inversely proportional to the

amount of fluid in the tank. The radiation signal is calibrated in terms of level provides the required measurement. The change in density will show effects in output. This can be operated even at high temperature and provides good accuracy and response.

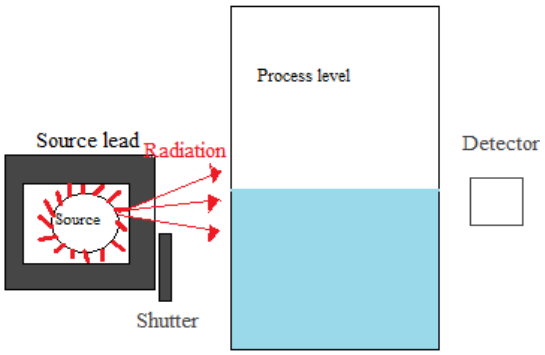

Figure 5: Radiation level measurement.

3. Dipstick level measurement

Dipsticks are easy and quick level measurement of liquid. The design of dipstick level measurement is simple. In this type of measurement a metal strip is used. The metal strip is connected to a handle. The handle is usually made up of plastic or metal. The metal strip is having markings and these markings indicate the level of the liquid. Normally the dipstick is inserted into the container in which the level is to be measured. And after a couple of minutes it is removed and the readings are noted.

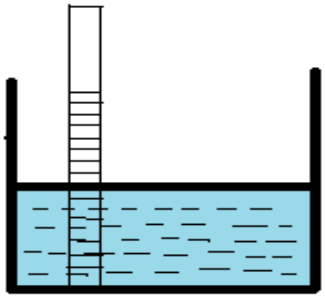

Figure 6: Dipstick level measurement.

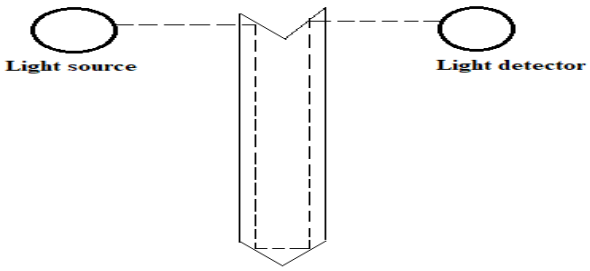

Figure 7: Optical Dipstick.

Apart from the simple dipstick, Optical dipstick type of level measurement is also used for liquid level measurement. In this type of measurement a light source is present and the source is reflected from the mirror and passes through the oblique end of the dipstick, and enters the detector after a reflection from the second mirror. When the oblique end of the dipstick comes in contact with liquid, the internal reflection properties are altered and the light no longer enters the detector. To move the instrument up and down and to measure its position a suitable mechanical drive is used. Thus the liquid level is monitored. This is applicable in larger or deeper tanks.

4. Float displacement type level measurement

The float displacement method works on Archimedes Principle. When a body is placed in a liquid, it is buoyed (bounced) up by a force which is equal to the weight of the displaced liquid, and the evident change in the weight of the body is directly proportional to the level of the liquid in which the setup is placed. A torque tube is the most commonly used for this setup. The displacer is attached to the torque tube and the rotary motion is used for the control. Displacers can be used for both point level and

continuous level indication. Floats and displacers are present in many shapes like cylindrical, spherical etc. Displacer float switches can be used to detect the high and low levels in the tanks and vessels.

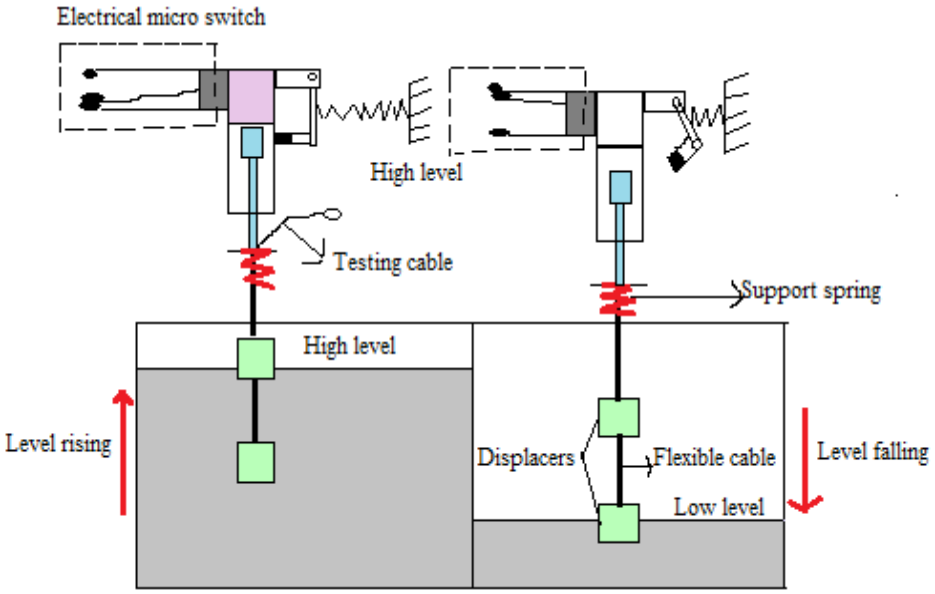

Figure 8: Float displacement type level measurement.

This gives high accuracy. Can be mounted internally and externally. This is highly reliable in clean liquids. For externally mounted apparatus the cost increases. Only limited range can be used. More length is difficult to balance and is bulky.

5. Spark plug level measurement

The spark plug level sensor is basically a stainless steel sensor probe. The principle is based on grounding the sensor in contact with the sodium. This consists of a central electrode which contain resistors. As the liquid sodium level rises and touches the end segment of the level probe, the electronic circuit gets grounded through the sodium. This gives indication liquid metal contact with probe. The main advantages of this type of level measurement is that the maintenance is easy. The electronics and the construction is simple. However, above 250°C the sodium vapor deposition short circuits the probe and this gives spurious signals.

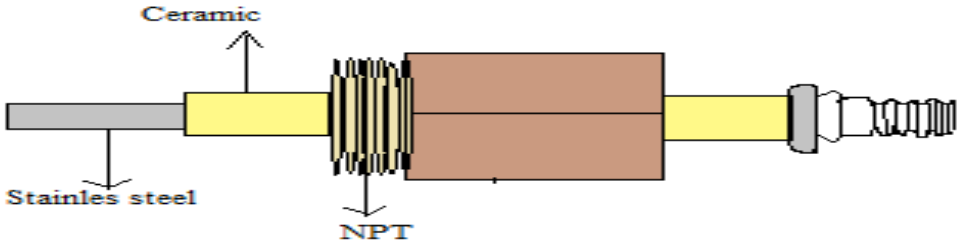

Figure 9: Spark plug level measurement.

The operating temperature of the spark plug will be the actual physical temperature at the tip of the spark plug.

6. Optical type level measurement

The main property used here for level measurement is the reflection property. If we used is an optical fibre level detector then refraction will be the property. This type of measurement can be done for both point and continuous level measurement. The infrared or visible light sources can be used for the detection of the level. Light is passed to the liquid whose level is to be detected, the corresponding reflection is received by the light sensors which are mainly quartz crystals or prisms. This measurement can be calibrated in terms of level measurement units. Due to the refractive index of liquid prism when there is no liquid present the light intensity will remain the same and in presence of the liquid the intensity gets diminished. These sensors can be also used in corrosive, organic and aqueous liquid according to the proper choice of material of construction and placement location. The alternative application for optical sensors is by using laser light. But laser lights are limited use for industrial purposes because it is difficult to maintain and more costly.

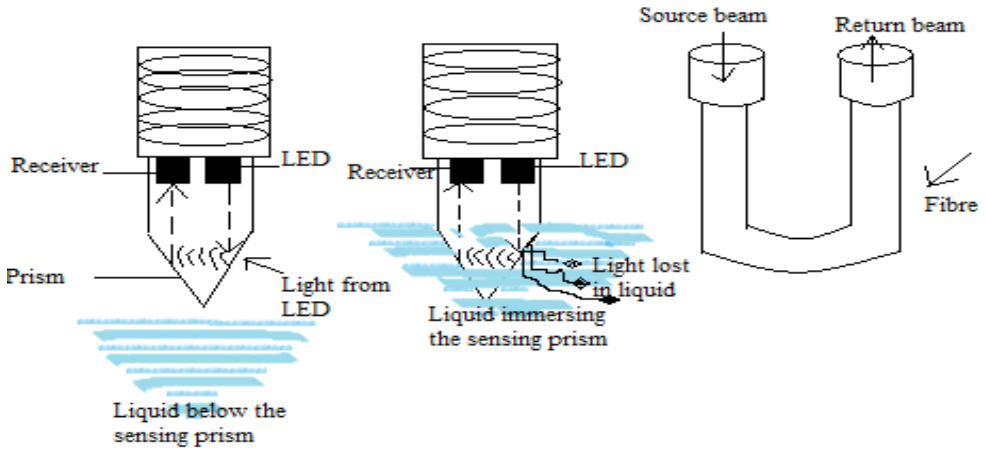

Figure 10: Optical type level measurement.

The cost is low and it is small device set up. This measurement gives high precision and accuracy. The set up should be cleaned or else it will affect the performance. If there is any change in the reflectivity of the medium the process is adversely affected.

7. Ultrasonic type of level measurement

In ultrasonic type of level measurement, the ultrasonic waves are used. This method is used for both point and continuous monitoring. The propagation time of the sound waves in the ultrasonic region is the principle used for level measurement here. Attenuation of the vibrating diaphragm face is one of the method in which it operates. The other one is absorbing the acoustic energy when it is travelling towards the receiver from the source. The time required for the echo produced to return is measured. There are two different orientations for the ultrasonic sensor. One is when we place it at the top of the tank/container, it is the region where the speed of the sound will be around 330 meters per second. Here the vapor space depth above the liquid is measured. Another orientation is when we keep it at the bottom of the tank/container, the depth of the liquid in container is measured. As the sound velocity changes proportionally with the square root of the temperature, the temperature compensation can be provided. When we apply an electrical signal, the required mechanical wave is generated. For this purpose piezoelectric crystal is used. Smooth surface are used for better reflection because rough surfaces produces diffused reflection. Turbulence and foam have a major role in this type of measurement as they prevent the sound wave from being properly reflected. The ultrasonic transducer is used both for transmitting and receiving the acoustic energy. So it is exposed to mechanical vibrations called ‘ringing’. The vibration should fade before the echo signal is processed. There is a small range near the face of the transducer, where it is not able to detect the object. This is called blanking zone.

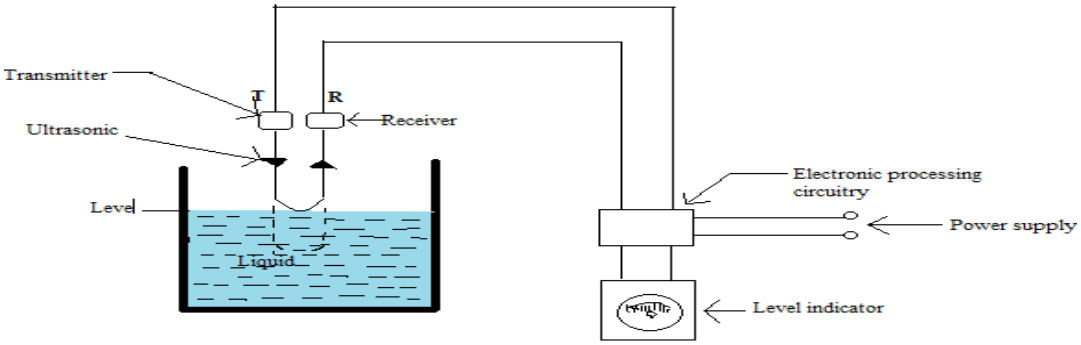

Figure 11: Ultrasonic type level measurement.

The advantage of this setup is that only low maintenance is required. Self-cleaning can be done. Some disadvantages are that temperature compensation is required, these are subjected to multiple interferences. Dirt and rough reflecting surface may affect the accuracy.

8. Float actuated type resistive level measurement

The relationship between the resistance and the current flow is been used here for accurately measuring the level. The commonly used design is a probe which consists of two conductive strips. The gold-plated steel will be at the base of one strip and the other strip will be of an elongated wire resistor. They form a complete electric circuit by connecting it together at the bottom. A low voltage supply is given to the upper end of the strips. A process material is present and a flexible plastic sheath is used for isolating the strips from the process material. When the level of the process material rises, the pressure forces/pushes the resistance strips together up to the interface. This shorts the circuit below the interface level and the resistance gets reduced proportionally. Here the liquid level position is converted to an electrical signal. The float is used as the primary transducer. And this transforms the variation in the liquid level to suitable displacement. The displacement is sensed by the secondary transducer which is a resistive potentiometric device. This device converts the displacement to electrical signal. When there is a liquid level change the float starts to move according to this change in liquid. The variation in float position triggers the arm. The slider then moves over the resistive element of the potentiometer. The resistance of the circuit changes and this change in resistance is directly proportional to the liquid level in the tank.

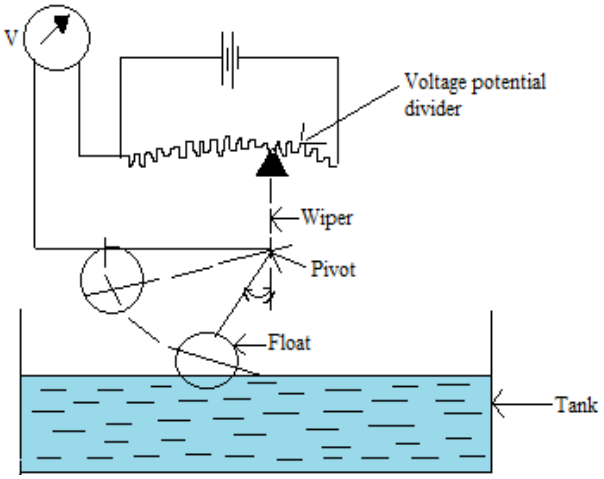

Figure 12: Float actuated resistive level measurement.

The level can be continuously recorded with the addition of contact probes. The danger can be eliminated by using low voltage. To any desired point signals can be transmitted. This setup is simple to calibrate. The disadvantage is that it is unsafe to use this in explosive atmosphere. This require large number of contact rods and can be corroded by corrosive liquids. If there is any variation in the conductivity of the liquid serious errors may occur.

9. Radar type of level measurement

In the RADAR type of level measurement, a radar sensor is used. The microwaves are transmitted by the antenna system of the radar sensor to the surface of the liquid. The waves get reflected by the surface of the product and is received back by the antenna system. The time interval between the emissions to the reception of the signals is proportional to the level of the liquid in the container. Both radar type of level measurement and ultrasonic type of level measurement use time of flight concept but the only difference is that in ultrasonic measurement sound waves are used whereas in radar type of level measurement radio waves are used. Radio waves have very high frequency and are electromagnetic in nature. The radar level instruments works at its best when there is a large difference in permittivity between the two substances. The power reflection factor (R) is defined by the ratio of reflected power to transmitted power at any interface of the material in the tank. Probes are used in guided-wave radar instruments. The probes can be single metal rod, parallel pairs of metal rod or coaxial type of rod can be used. Non-contact radar instruments depend mainly on antennas. The antennas should be kept cleaned and dry so they are separated from the interior of the vessel by placing a dielectric window which is made of substances like plastic which are relatively transparent to electromagnetic waves.

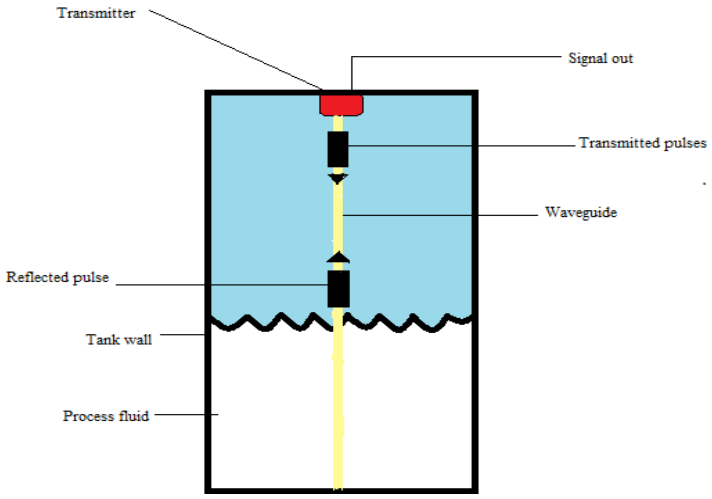

Figure 13: Radar type of level measurement.

The accuracy of the radar level instruments changes as the temperature or pressure varies. These are the factors influencing the dielectric constant. When the radar level instrument transmit the energy some gets reflected back to the source and the remaining propagates further. The guided-wave radar instruments receives a greater percentage of their transmitted power when compared to the non-contact type radar level instruments. There is no moving part present in these type of level instruments. The setup has low maintenance and easy installation. The disadvantages are they are not applicable for interface-interface measurement. If vapor is present, it weakens the radar signals and this reduces the accuracy of level measurement.

10. Mutual inductance level probe type of level measurement

The mutual inductance level probe (MILP) type of level measurement works on the principle of change in mutual inductance with the change occurring in level of liquid metal like sodium which have good electrical conductivity. This setup consists of a primary winding and a secondary winding. The windings

are wounded on a non-magnetic former in a bifilar fashion. The primary winding is excited with an AC constant current source. This produces an alternating flux which induces an EMF in the secondary. As the sodium level rises, an alternating flux induces an EMF in the liquid metal. Since the liquid metal is conductive and continuous, the induced EMF produces alternating current in liquid metal. These circulating currents are called eddy currents and produces flux which opposes the main flux and the net flux is reduced. Thus the secondary EMF also gets reduced. The decrease in the secondary EMF is linearly proportional to increase in liquid metal level. When the temperature of the sodium is varied, the resistance of liquid metal also changes causing a variation in eddy currents. Thus the secondary voltage changes. Thus, the secondary voltage of the probe is a function of liquid metal level and also its temperature. Temperature compensation is required and is carried out by various methods. The level probe assembly consists of a stainless steel pipe called "pocket" and a probe. The probe consists of a sensing element, a bobbin supporting tube probe flange, and terminal box. The probe is placed inside the pocket. The sensitivity of the level probe can be increased by increasing the number of turns of the windings.

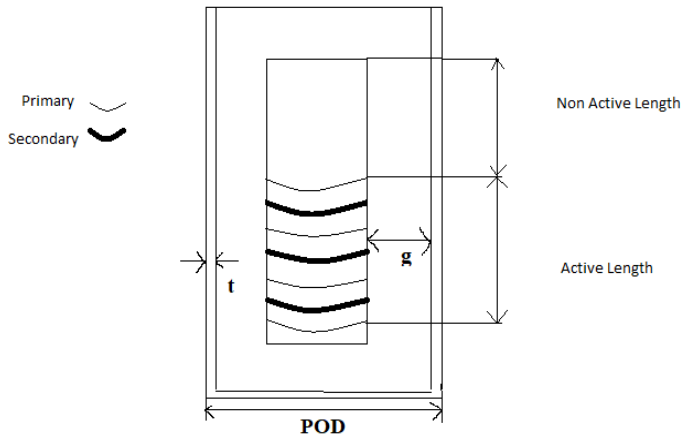

Figure 14: Schematic of Mutual inductance level probe (MILP).

POD – Pocket outer diameter, T – Thickness of the pocket, AL- Active length, NAL – Non-active length. The active length is the bobbin length and the non-active length is the area where there is no winding.

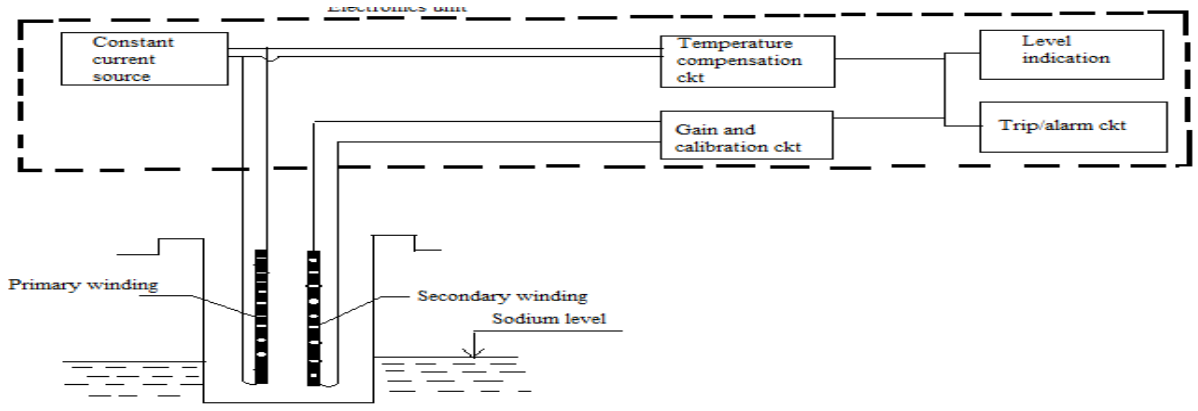

Figure 15: Mutual inductance type continuous level probe.

The advantage of the Mutual inductance level probe over resistance type level probe is the former works on non-contact principle and the latter works based on its contact with sodium. Since the mutual inductance level probe is kept inside the pocket its maintenance is easy. The non-wetting of sodium with the sensor does not affect the operation of the mutual inductance sensor.

11. Conclusion

Various methods of liquid level measurement are presented in this paper. Each level measurement technique has different working principles. Every level measurement system includes the interaction between the sensing device, the element or the system, and the type of substance inside the container. In this paper we thoroughly reviewed various techniques of level measurement, the kind of sensors used, their working principle and the advantages and disadvantages of the level measurement techniques. A method of measuring liquid metal level by making use of mutual inductance principle is also depicted in the form of a mutual inductance level probe. This probe is a non-contact probe and is used quite frequently in liquid metal systems like fast breeder reactors which have liquid sodium as the liquid metal coolant. Research and development is still in progress in these sensing techniques to make them more compact and maintenance free.

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