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Problems in the Non-Intrusive Sensing of
Flooded Battery Electrolyte Levels:

Capacitive, Ultrasound and Infrared Technologies

Introduction

The use of flooded battery cells in electrical power backup systems has always necessitated a high use of resources and personnel. Although long lasting (25 years), the batteries themselves are expensive, and must be maintained properly if this lifetime is to be achieved.

Proper maintenance dictates visits by service personnel on a monthly basis, to check the levels of the acid electrolyte in the cells, which must not be allowed to fall below the level of the plates or internal group (bus) bars.

Also, in several countries legislation dictates that the level of the electrolyte must be monitored at all times, either by remote means or by regular personnel visits.

Remote sensing of the electrolyte level in batteries has been available for some time, usually by inserting a sensor physically into the electrolyte via one of the cell filler caps. The sensor then uses either a float switch or sensing electrodes to determine the level. Insertion into the electrolyte, however, is not the most desirable method since the designs of many cell types make this difficult if not impossible.

It is, therefore, desirable to determine the electrolyte level from outside the cell container, without any intrusion into the container or the electrolyte.

Sensing electrolyte level: Capacitance, Ultrasound and Infrared

All these three technologies have the capability to measure battery electrolyte from outside a cell container without penetration of the container or the electrolyte. They are of course limited by certain characteristics of the containers; none of the three can 'see' through metal containers, and infrared cannot penetrate an opaque container such as is used for VRLA batteries. However, since all flooded battery cell types are housed in clear, transparent containers, and NiCad flooded battery containers, although clouded, are not opaque to infrared, these problems don't arise in the real world.

Although capacitance, ultrasound and infrared are all capable of sensing an electrolyte level, i.e. 'electrolyte' and 'no-electrolyte', there are more difficulties to sensing accuracy and reliability than would first appear.

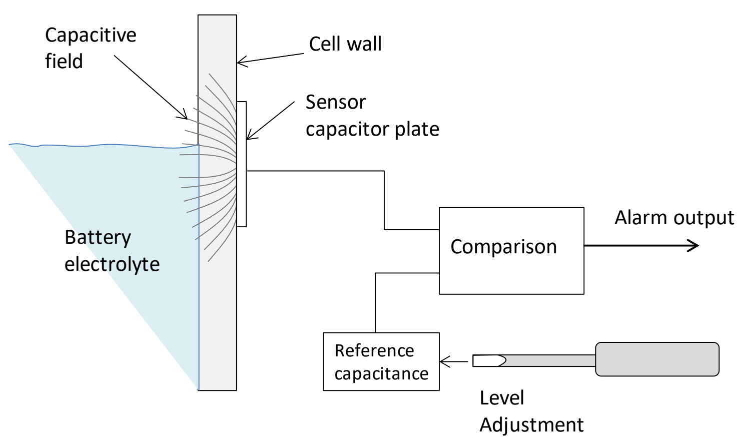
Capacitive sensing of liquids

Capacitive sensing of near objects is a well-known technology; Smartphones, iPads and almost all touch screen devices use capacitive sensing to detect the user's commands. It can be a sensitive method and will detect objects many inches away from the capacitive sensor itself.

A capacitive sensor works by comparing a known (reference) capacitor with a sensor plate capacitor (ground being the other plate), which alters its capacitance when an object in its field is brought near or moved farther away. In battery cells, this object is the electrolyte which, to the sensor, is either 'there' or 'not there'.

If made sensitive enough capacitance can detect liquids at a distance through plastic and glass, and is therefore an attractive sensing technology for lead-acid cells. Of the three technologies under discussion however it is the most sensitive to outside influences.

A basic diagram of a capacitive sensor on a cell is shown below:



The principle of the capacitive electrolyte sensor

The level at which the electrolyte makes a difference between the reference capacitor and the sensing plate can be changed by adjusting the reference value.

Due to its widespread usage in consumer goods capacitive sensing is an attractive technology for detecting objects (liquids) inside a container; however there are some drawbacks when using this technology for sensing electrolyte levels.

- The sensor must be set up in position on every cell, by calibrating the reference capacitance. This is fiddly, and can only be tested by removing some electrolyte to check that the sensor will detect the level at the correct position.

- The sensor can be affected by metal or the human hand in close proximity to the sensor, even if shielding techniques are used to prevent this.

- The sensor must be able to detect a liquid through the cell container wall. Cell containers are of different sizes and wall thicknesses, therefore the capacitance seen by the sensor plate will be different for different cells; once again the sensor must be adjusted to take account of this.

- The strength of the acid electrolyte can affect the capacitance experienced by the sensor plate, and therefore the level at which the sensor trips. Therefore the charge state of the cell can affect the tripping level, which is not desirable.

- The sensor must be sensitive enough to detect the presence of acid through the cell wall; unfortunately, this means it can sense metals too. In certain cells the presence of lead plates and group bars too close to the container wall means that the sensor field can be swamped by the metal, and sometimes cannot sense when the acid has fallen below the set level.

- When the electrolyte level is close to the tripping point, the sensor is at its most sensitive, and a high amount of electrical noise in close proximity can affect the sensor, causing occasional momentary false alarms.

These problems mean that it is difficult to be one hundred percent certain that a capacitive sensor will work correctly on a particular battery system without carefully setting up every sensor and testing by electrolyte removal to ensure reliability.

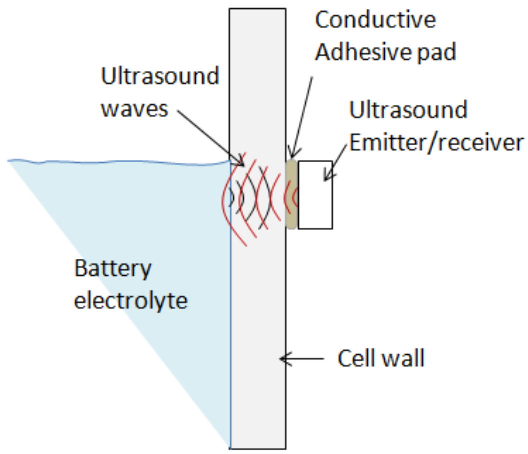
Ultrasound sensing of liquids

Ultrasound is the term used to describe sound waves of frequencies above the ability of humans to hear, although not some animals, bats for example. Ultrasound sensors basically generate percussive waves of over 20 thousand cycles per second, and look for a response when the waves strike an object in their path and are reflected back to the sensor.

The time taken for the sound wave to travel to the object (in this case the electrolyte, or other objects in the container) and return is a measure of the distance the object is from the sensor. However the closer the object is to the sensor the more difficult it is to be accurate, due to the extremely short distances involved and the difficulty of timing the returning waves accurately.

In battery electrolyte level sensors, the sensor is attached to the side of the cell and ultrasound waves are directed into the cell and electrolyte. The sensor must be attached by a special conducting cement, which enables the cell wall to become part of the sensor ultrasound conduction scheme, transmitting the sound waves to the electrolyte and receiving the response from the liquid (or not).

Many sensors state that they can only operate beyond a certain distance from the sensor, 20mm for example. In electrolyte sensing the electrolyte itself is difficult to sense, however when it is not present the sensor should be able to more reliably detect other objects within the cell and the difference allows a decision to be made on the electrolyte level.
The principle of an ultrasound electrolyte level sensor is shown below:



An ultrasound electrolyte level sensor

As with all non-intrusive liquid sensors, there are problems which must be overcome.

- The first is contact. In order to transmit the ultrasound signal correctly, the sensor must have a bond between the sensor and the battery container capable of transmitting the sound waves. In the same way a hospital ultrasound scanner must use gel to conduct the sound waves to the body of the recipient the electrolyte sensor must use a conductive bonding adhesive. This can sometimes contain air bubbles which cause distortion in the measurements, leading to false alarms.

- It is necessary to wait until the special conductive adhesive has set in order to calibrate the unit, and this can take up to 24 hours or more. Only at the end of this time will the user know whether the sensor will have to be removed & replaced because there are air bubbles present in the adhesive cement; this is not an unknown situation. The user must then wait another 24 hours for any changed out sensors to set before calibration is possible.

- Ultrasound sensors can calibrate automatically, but this must be initiated manually, after the cement has set and may take some time; thus several visits to site are necessary before the sensor can be seen to be operational.

- Once again container wall thickness is different for different sizes of cells and this must also be taken into account when calibrating the sensor.

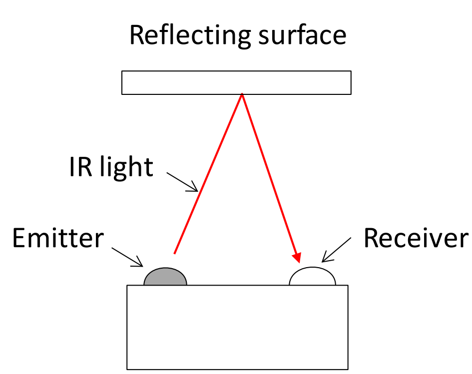
- As with the capacitive sensor, the only way of ensuring that the sensor is working correctly is by removing electrolyte until the sensor alarms. In a system of many cells this can be a time consuming process and very resource intensive, particularly in remote sites.

Infrared sensing of liquids

The IR sensor makes use of infrared light, that is, light of a particular wavelength just above the red scale in the electromagnetic radiation spectrum. Certain electronic components called diodes can be used to emit infrared (the emitter) and other components, also diodes, can be used to receive & measure infrared (the receiver), and convert it to an electrical signal proportional to the amount of received light.

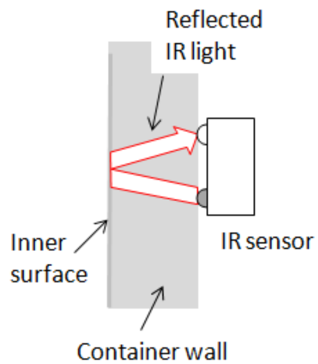
The emitted infrared light will be reflected from any object placed in front of it. If the receiver is placed near the emitter, a percentage of the reflected light will fall on the receiver. The amount of reflected light at the receiver depends on the strength of the emitted light, the distance from the object, and how reflective the object is.

The principle of an IR sensor is shown below:



The principle of an IR sensor

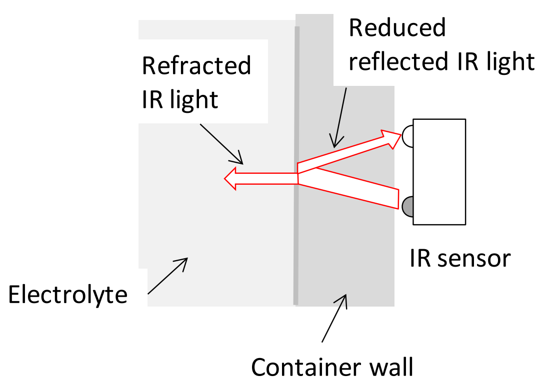
There are certain properties which make infrared a good detector of liquids in a transparent container. The sensor can be attached to the outside of the cell such that it emits IR light into the container, and a high proportion of the emitted light will be reflected from the inner surface of the container back to the receiver.



A high proportion of the emitted light is reflected back to the receiver

So far so good, but how will the sensor detect the acid electrolyte?

A very useful property of liquid within a transparent container is that any light hitting the inner surface of the container will be refracted by the liquid in contact with it. That means a large proportion of the emitted IR light hitting the inner surface of the container will be diverted by the action of the liquid, and not reflected back to the receiver.



Liquid refraction of emitted IR light

The action of the electrolyte refraction can reduce the reflected light by more than half, so detecting the difference between 'electrolyte' and 'no electrolyte' is very reliable.

Although infrared is the most reliable method for the detection of electrolyte levels in transparent containers, there are still problems which must be overcome. Some of these are the same as for capacitance & ultrasound sensors:

- As in the capacitive and ultrasound sensors the thickness of the cell wall plays a part. Due to the angles of reflection the sensor will reflect different amounts of light depending on wall thickness. Unfortunately, the producers of the sensor cannot know the container thickness at manufacture, so it is difficult for the factory to determine a default value at which to alarm.

- Ambient light conditions can interfere with the measurement of the reflected IR light, since many light sources contain infrared. In battery rooms ambient light conditions can change dramatically when, for example, the electrolyte level sensors are installed in daylight or with all the lights on. After the installation is complete the lights will be switched off and the room is likely to be in darkness. Once again it is not possible at manufacture to anticipate the levels of light necessary to make an alarm condition.
- The presence of lead plates and group bars close to the cell wall can also reflect IR light from the sensor, however this is not a highly significant issue as the reflective interface is the inner surface of the container wall.

All the above conditions contribute to the difficulty of determining the correct alarm level to trigger at when the sensor is being manufactured.

A patented new design -- The Eagle Eye iX sensor

Eagle Eye Power Solutions recognized that what was needed was a reliable electrolyte level sensor that could be quickly and simply fitted to the cell and that would require no calibration or setup, but could be demonstrated to work 'out of the box', giving the user complete confidence in its reliability and ease of use.

Whichever technology was employed, the new sensor should be non-intrusive, and able to overcome all the problems associated with non-intrusive liquid level sensing. After assessing the various technologies available, infrared was chosen as a basis for development as it was extremely reliable in the detection of 'electrolyte' or 'no electrolyte'.

The result of many months of development and testing was a patented sensor that could do exactly what was required. It could be easily fitted to a cell and, in the normal temperature range for a standby battery, needed no calibration or setting up, but could be demonstrated to quickly and accurately detect the electrolyte level on any cell, even before fitting. The thermal runaway protection alarm could also be adjusted for abnormal temperature conditions.

Although based on infrared technology, **the patented iX sensors** use a completely new patented method to eliminate all the problems associated with using infrared to sense battery electrolyte. The iX sensor therefore is extremely accurate and reliable, and consistently repeatable time and time again, for any type or size of cell.

An extensive testing program on many different cell types, in different positions and in extremes of ambient light and temperature has confirmed that the iX sensor is consistently dependable. To date in field tests it has not experienced a single failure in accurately detecting an electrolyte level.

The sensor is supplied with a cradle which allows the sensor to be easily relocated if the cell has to be changed out. All that is required to install the sensors and commission them is to attach the cradle to the cell in the correct position and connect the sensor to the monitor. When the power is applied to the sensors they will begin working automatically. No setup is required.

A further advantage of the iX sensor is that maintenance testing is made simple. Until now, to test an electrolyte level sensor, any cell with a sensor attached has to be drained to the point at which the sensor should detect a low level, and the sensor monitored for an alarm. Once the sensor has been tested the cell must be topped up again.

Testing level sensors this way is time consuming, messy and dangerous (the electrolyte is after all Sulphuric acid!).

With the iX sensor, instead of having to drain electrolyte from the cell in order to test that the sensor is working as it should, the sensor can be unclipped from its cradle, held against the cell and moved from below the current electrolyte level to above. The sensor will light up its indicator LED to show the alarm level; at which point all that is required is to clip the sensor back into its cradle and the test is complete, perhaps one minute from start to finish.