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Measuring of Liquid Level Using Remote Grounded Capacitive Sensor

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Abstract: In this study, the planning and implementation of measuring a liquid level with the help of remote grounded capacitive sensor is described. The electrodes of a capacitive sensor are made up of low-cost materials mainly an insulated wire (PTFE) and a stainless-steel rod. A basic relaxation oscillator and a microcontroller are used in the interface circuit. The sensor is connected to the interface circuit by an active protected wire. The active-shielding circuit's stability is surveyed by thinking about the parasitic parts of an interconnecting link and the sensor. The device was put in the test by recording how much tap water was used in a grounded steel container. Now, when the level range is about 70cm, then the system has an error smaller than 0.34mm and a 0.09mm of resolution for measuring the time of around 19ms.

Keywords: microcontroller, capacitive sensor, liquid-level measurement, relaxation oscillator, active shielding

I. INTRODUCTION

Fluid levels in streams, reservoirs, and compartments can be observed utilizing electrical capacitance between the two lowered electrodes in fluid [1]. Minimal expense (sensors might be created by using the technologies which are affordable), low power utilization, solid linearity, and a simple adjustability to the application calculations is only couple of the upsides of using a capacitive sensor for fluid level estimations.

Depending on the kind of liquid, capacitive liquid-level sensors have distinct functioning mechanisms [2,3]. To stay away from a short circuit in conductive fluids, so one of the two sensor terminals should be protected. Since, the fluid goes about as a channel below to 3+ air in liquid state contact, the dielectric's capacitance is basically the terminal protection. The air in liquid state contact is below the electrode insulation, as well as the air is between the electrodes, which reduces capacitance.

The electrodes, on the other hand, do not need to be insulated while working with non-conductive liquids. The dielectric is below the air in liquid state interface. The electrode's area is under the contact of air in liquid state grows as the level of liquid rises the capacitance for both types of liquid.

Floating capacitive sensors (with neither electrode grounded) and grounded capacitive sensors (with both electrodes grounded) are the two types of capacitive sensors [4]. (Sensors with one electrode grounded). Because of security concerns or functional limitations with capacitive floating and grounded sensors at this point they are most essential in specific implementation like the checking of level in a conductive liquid of a metallic holder which is grounded [1,6]. A non-linearity error of around 0.6 mm (i.e. 0.1%) and an objective of 0.1 mm for an assessment extent of a 60 cm claimed by Reference [6]. Reference [7], then again, for the case of a non-linear error and a goal of 1.0 mm over an estimating scope of 70 cm.

Applications such as monitoring water levels of the oil tanks, the sensor and its electronics are usually separated in some cases, the sensor is associated with the interface circuit through a safeguarded wire to lessen the impacts of outside noise/impedance. Standard passive shielding is inefficient because of the parasitic capacitance of the connections for grounded capacitive sensors, which can be substantially larger than the sensors and changes depending on environmental conditions. To link the grounded capacitive sensors with the circuit, the active-shielding methodology [4] is extensively used. This entitles continuously sampling of the inner conductor's potential and sending it to the shield via an amplifier. This report shows the design and development of a remote grounded capacitive sensor used in a liquid level measuring system. The influence of parasitic components on the active-shielding circuit (both the connecting cable and the sensor) is thoroughly explored. The device was put to the test by detecting the degree of conductive fluid (regular water) in a grounded metal holder.

2. SENSOR

Figure 1 illustrates a sensor prototype. The sensor has two electrodes and a height of about 1m, one of the electrodes is insulated for monitoring conductive liquids,

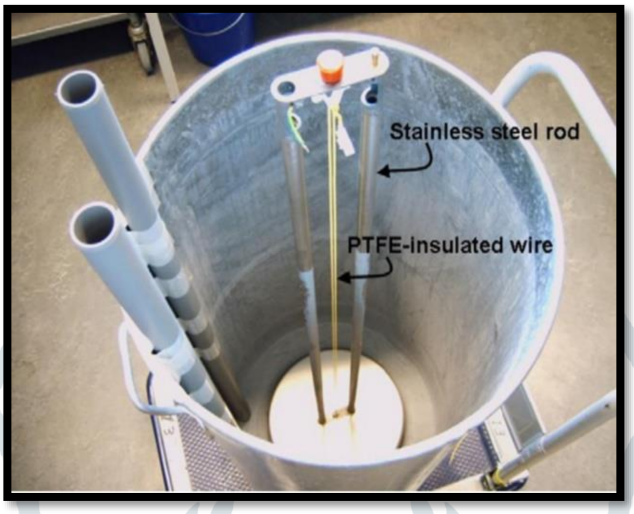

Figure 1. A capacitive liquid-level sensor prototype within a metallic container.

In activity, the non-protected terminal is a tempered steel rod that is connected to the ground because insulated electrode is a protected by a wire and have both inner and outer distances of (1.0 mm and 1.6 mm). As, the capacitance of a sensor is proportional to insulating thickness and dielectric constant, a non-permeable, a temperature-steady, non-stick, consumption safe material like PTFE is required (commonly known as "Teflon"). This arrangement solves the problem of one of the ends of the wire which is being sealed while also tripling the sensor capacitance [6]. Using a wire as an insulated electrode is not advised according to early test results, because linearity and hysteresis are considerably reduced. The wire tension is adjusted using a piece of tough plastic at the top of the sensor.

2.1 Ideal capacitive sensor

The capacitance between terminals used to distinguish the degree of conductive fluids underneath the liquid-air hindrance is by and large identical to the capacitance which is utilized to recognize the degree of conductive fluids over the liquid-air boundary. The electrode arrangement for this capacitance is coaxial, which implies that one anode is the associated wire, and the other is the conductive liquid that surrounds the wire protection..

The value for the capacitance will be: -

$\{Cx = 2\ [2\pi\varepsilon o\varepsilon r/ln(d1/d1)]\ h\}$ ---------(1)

Where, εo-permeability of a vacuum (= 8.7552 x 10^{-2} F/m),

ε_r - dielectric constant (wire),

d1-internal diameter and d2-external diameter of a wire

h - level of liquid.

3. Circuit model

In Figure. 2a. [1] Cx (Ideal Sensor Capacitance) which is defined by equation (1), Rw and Cw are the Liquid Resistance and The Capacitance respectively [2,10], the current loop inductance is Ls. By ignoring the influence of impedance, the frequency rate of an excitation signal is considered to be high. (over 26KHz).

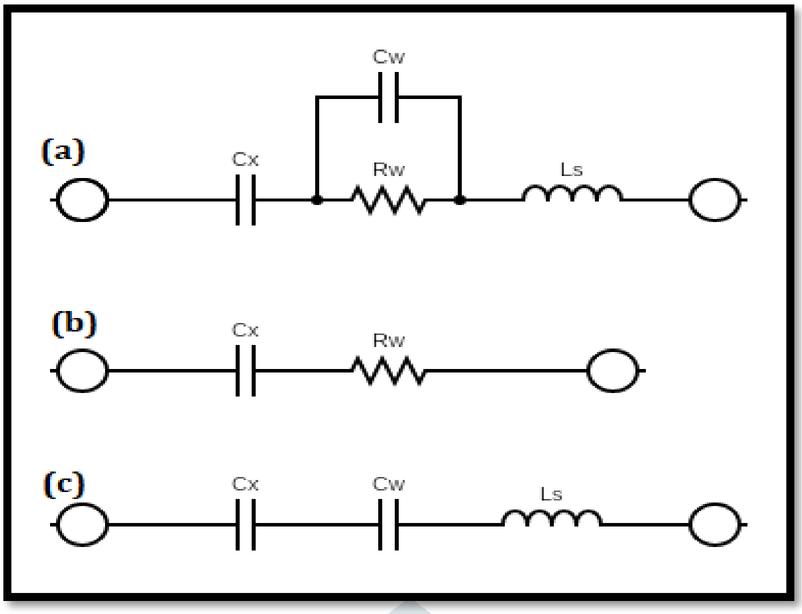

Figure 2. (a) liquid level sensor (b) low-recurrence (c) high-recurrence circuit diagram

When the conductive liquid and the repetition of excitation signals are low, Rw properties exceed those of C around tens to hundreds of kilohertz, and Ls' belongings can be dismissed. This brings the circuit model's complexity down to the level which is displayed in Fig. 2b, It is more like an optimal presentation (i.e., it essentially experiences the impacts of R_w). The (Section 3.2) will likewise have a restricted recurrence range.

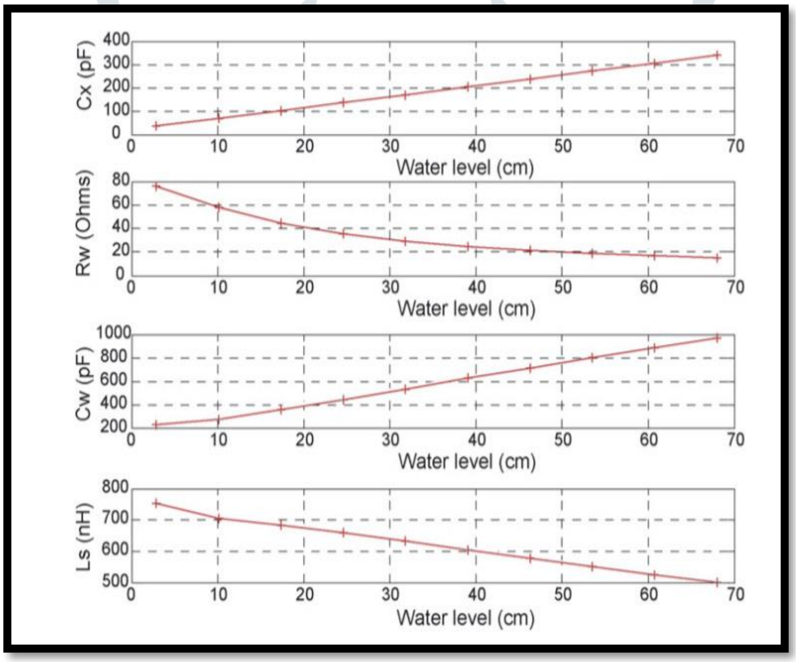

Figure 3. After effects of characterization of a liquid level sensor.

3.1 Sensor characterization

Using an impedance analyzer, the impedance of the expressed sensor model was estimated in the recurrence scope of 20 kHz to 15 MHz (Agilent 4294A). Utilizing the estimation information, the boundaries of a circuit portrayed in Figure 2a were recovered. Figure 3 portrays the characterization results for different regular water levels.

3.2 The Interface Circuit

Figure 4 portrays the interface circuit. The followings are the essential structure blocks:

1. a capacitance multiplexer that chooses which capacitance to measure,
2. a relaxation oscillator to convert capacitance to a period, as well as
3. a microprocessor that converts a period to a digital value

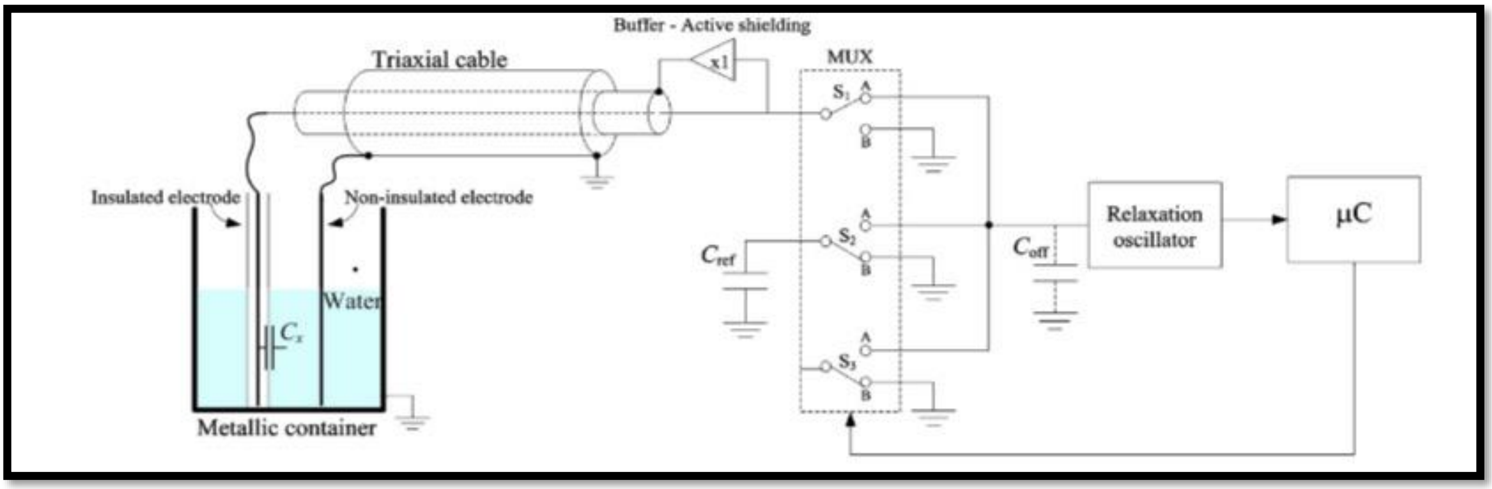

Figure-4 circuit for measuring liquid level with the help of remote grounded capacitive sensor.

The three-signal method [13] is utilized to auto-align the interface circuit as far as added substance (offset) or potentially multiplicative (gain) shortcomings (because of the progressions in temperature or the inventory voltage). This method utilizes three estimations: -

1. A sensor reading,
2. A standard measurement, and as well as
3. The measurement of offset.

The reference is (330 pF NP0) ceramic capacitor (Cref), the sensor's most extreme capacitance (Fig. 3). The capacitance (Coff.) is a capacitance that addresses the offset of an interface circuit rather than the sensor. Each of the three estimations is modified by the offset capacitance.

3.3 Multiplexer

The capacitance is joined to the still up in the air by means of a three-change two to-one multiplexer (MAX4560). Every estimation's fitting switch is set to situate A (the oscillator), while the other two are the sets to situate B. (i.e., associated with ground). For sensor estimation, switch (S_1) is put to situate, but sometime switches (S_2) and (S_3) are the set to situate B.

3.4 Relaxation oscillator.

Microcontroller after manipulating the multiplexer, the microcontroller then checks the period of an oscillator output signal. An embedded digital timer creates the digital number N [16], which is used to measure the period. The microcontroller uses a Microchip PIC16F876 operating at a frequency of 21MHz.

CCP1 and the inbuilt 16- bit Timer 1 capture module, which has a computerized timing goal of Ts = 200 ns, are responsible for the time measurement. To limit the effects of quantization, the controller detects 128 consecutive periods of an o/p signal. Now, in Table (1) the value of a computed digital numbers for each of the three criteria (Nx, Nref, and Noff) is shown.

4. Active shielding

As shown in Fig. 4, a triaxial link is associates with an interface circuit to the capacitive sensor. The principal safeguard utilizes a functioning protecting methodology (the shield is powered at a similar voltage as the internal wire). A current return route is provided by the grounded second shield.

Current circle is inductance between circuit and Cx is Lp, the obstruction of interjoined conductors is Rp. Cp indicates the capacitance between the main shield and link's internal conductor.

5. Results and Discussion

The productivity of proposed estimating framework was experimentally surveyed utilizing the design portrayed in Figure (1). The sensor was placed in a holder made of iron. with a 42-cm distance across and a 84-cm height that was associated with the framework ground. Despite the fact that the sensor was introduced in the holder's middle, its performance should to be similar in different areas (except for those where the sensor is extremely near the compartments shell). Tap water (conductivity 0.50 mS/cm) was used as the liquid, which was added to and drained from the container's bottom via two pipes. The amount of water added/withdrawn (which was manually monitored using test tubes) and the container's were used to compute the actual level value. A 1m connecting wire linked to the interface circuit.

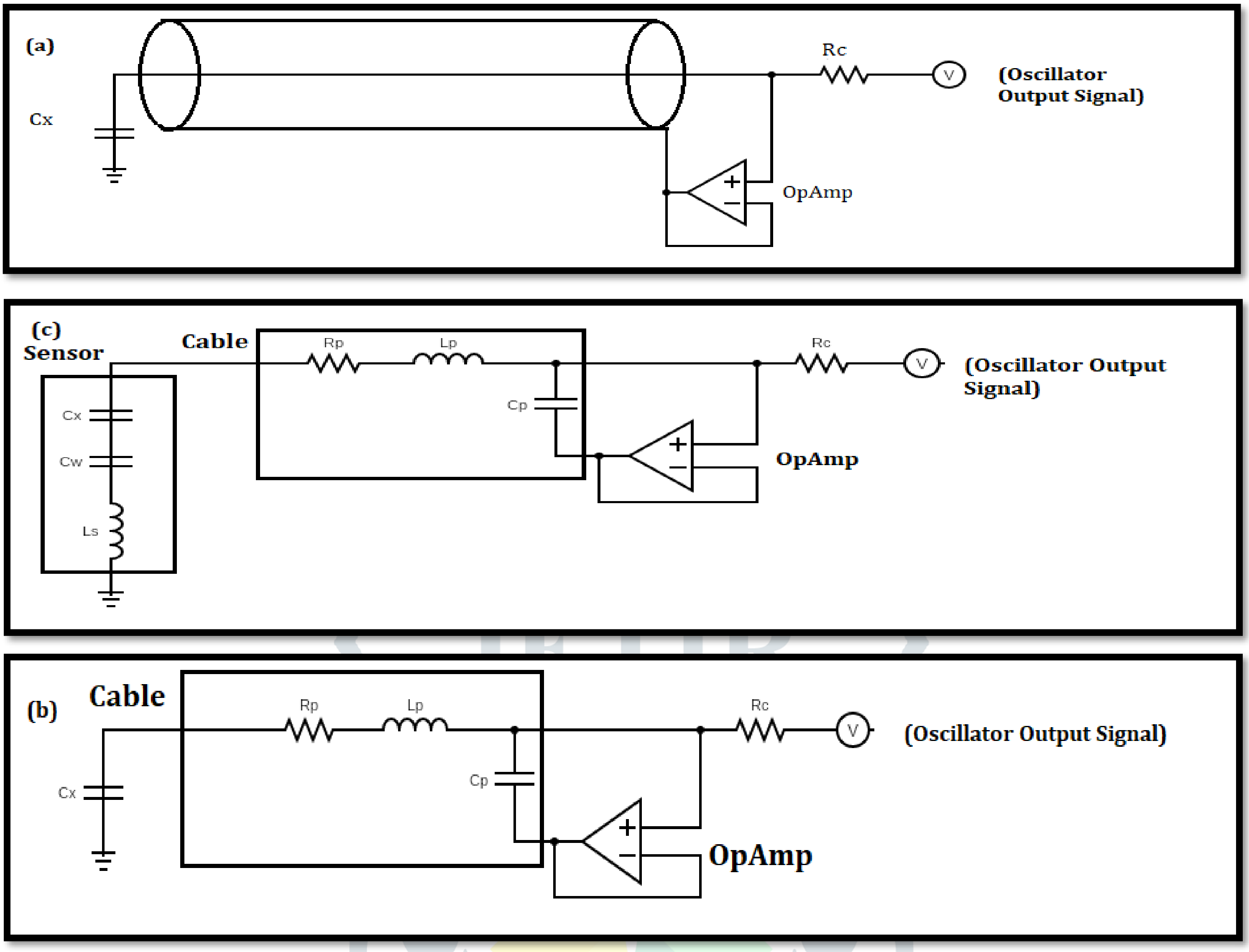

Figure 6: (a) Circuit for active shielding. (b) circuit that contains the connecting cable's parasitic parts. (c) circuit with parasitic parts from both the cable and the sensor

For a variety of commercial OpAmps with various sorts of bandwidths, the "electronic" security of the safeguarding circuit was tentatively examined at the highest water level (approx. 70 cm). The OpAmps were tested and the fb values were observed, and the outcomes were noted. Table (2) shows the theoretical stability criteria (fb 10.11 MHz), which match the theoretical stability criteria (fb 10.11 MHz) specified in section (4). Figure 7 shows the M ratio at various water levels ranging from 0 to 70 cm. To avoid true hysteresis effects, all of the values were gathered in rising mode. [M = 0.0146 h + 0.0870], where h is the liquid level, it is a straight line that fits the test data by using the least-square approach. Eq. 1 demonstrates this.

Table 2

Experimental Results of the stability test for several OpAmps with Different unity-gain Bandwidth (*fb*)

OpAmp	Nominal *fb*(MHz)	Measured *fb* (MHz)	Stability Result
OPA344	1	1.2	Stable
OPA337	3	3.6	Stable
OPA743	7	5.4	Stable
TLC071	10	11	Unstable
AD8655	28	30	Unstable
OPA350	38	64	Unstable

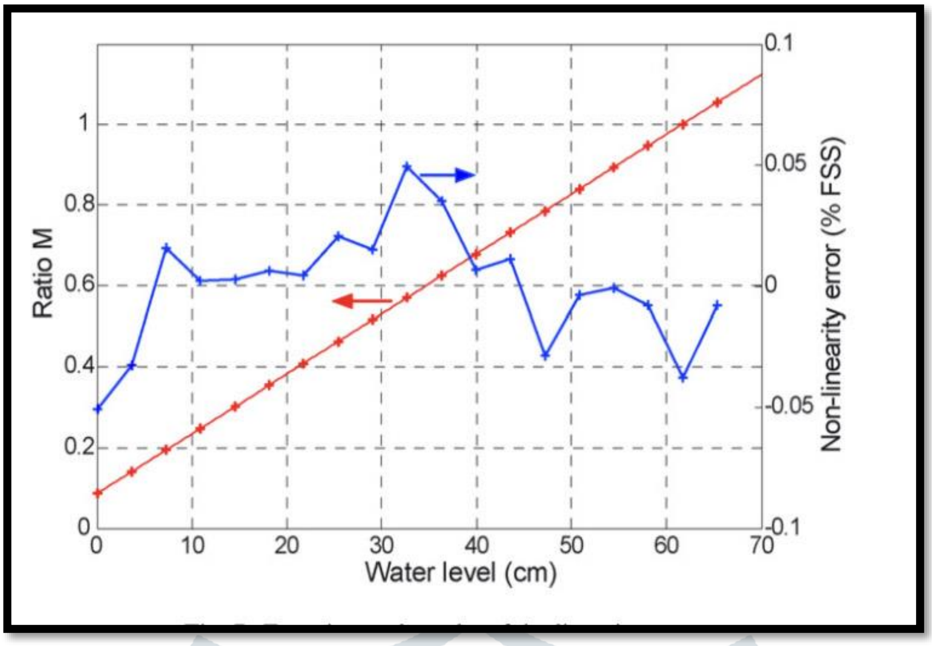

Figure 7. Linearity Test Results

For given steady water level, the standard deviation of the ratio M was less than 25 106, which is 0.02 mm. Two populations of M could not be distinguished at levels h and h + 0.10 mm, indicating that the resolution was more than 0.10 mm. A resolution of roughly 13 bits is achieved over a 70 cm level range.

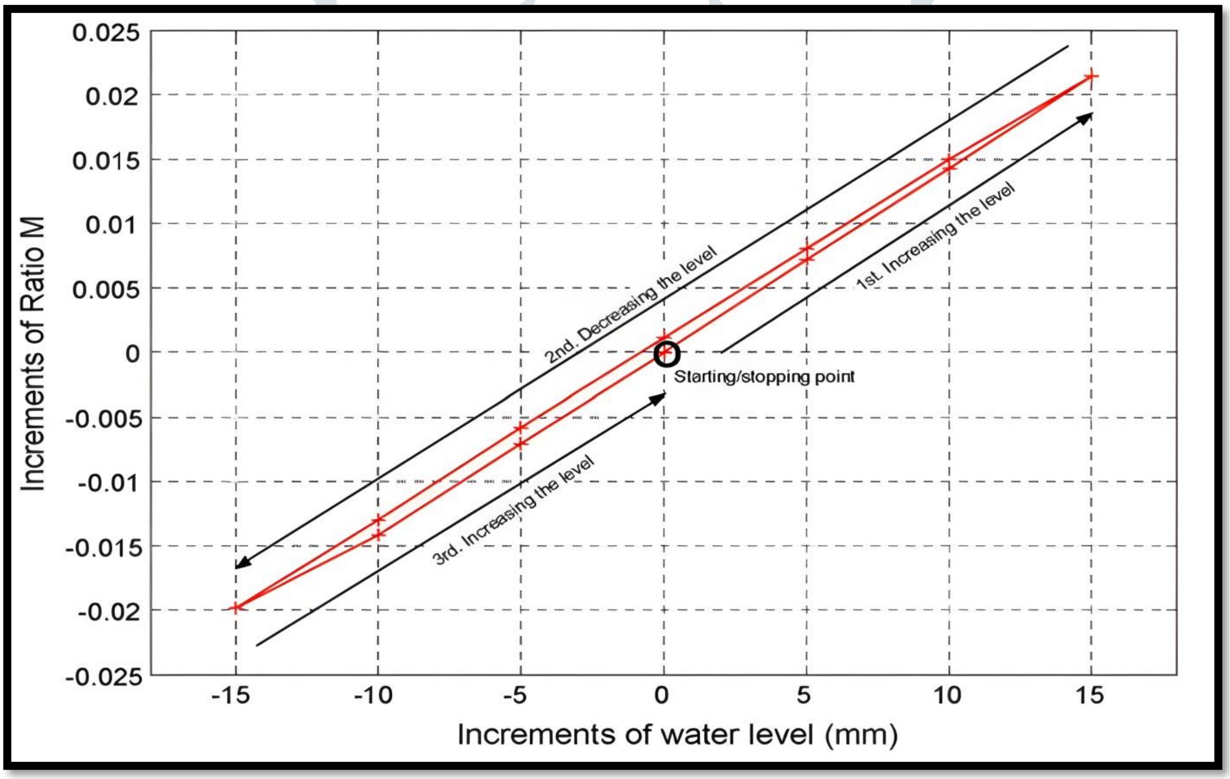

Figure 8. Experimental effects of a hysteresis test.

For a long time, the amount of M and the temperature of the water were constantly observed. The studied Temperature range is between (25 and 30C), and the Temperature Coefficient (M) was about 201 106 C1 (see Figure 9), comparable to (0.14 mm/C) at the highest water level. The sensor system and the liquid level are equally to blame for the temperature sensitivity.

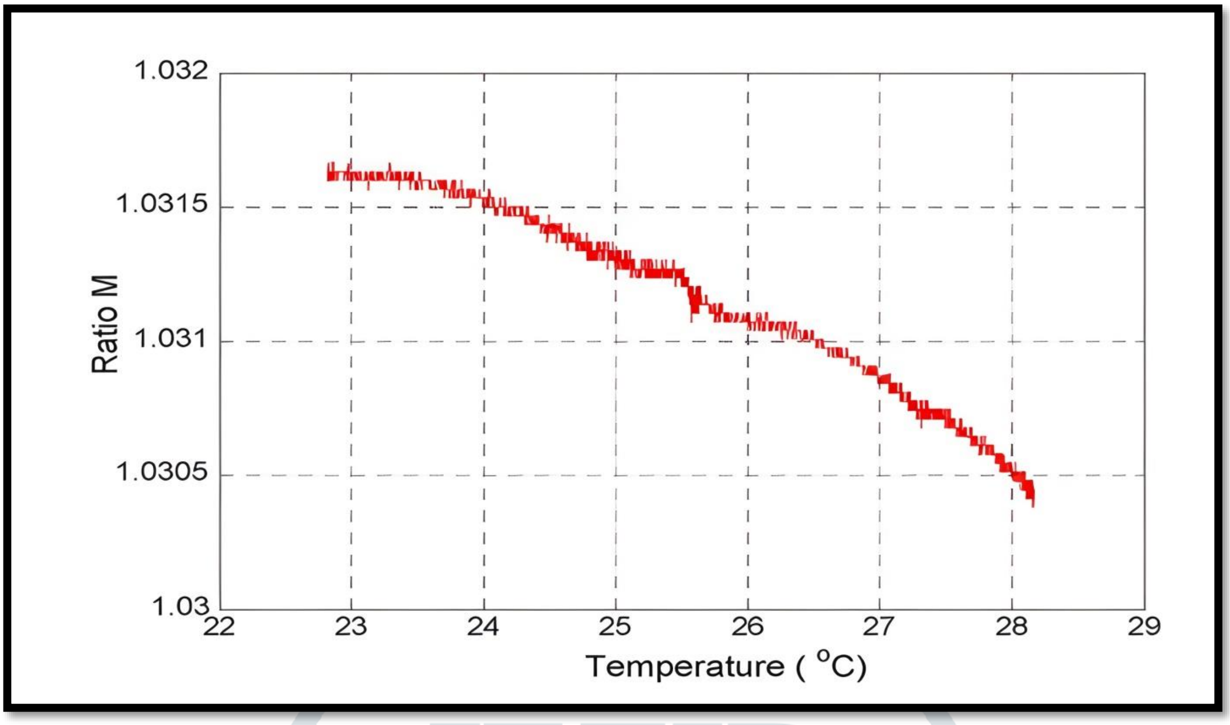

Figure 9. The Experimental effects of a temperature effects.

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