

Modified Ultrasonic Liquid Level Transducer Using Wave Intensity as the Informative Parameter

^{1,*}Haraprasad MANDAL, ²Madhuchhanda MITRA
and ²Satish Chandra BERA

¹ Department of Applied Electronics and Instrumentation Engineering, Saroj Mohan Institute of Technology, Guptipara, Hooghly-712512, India

² Instrumentation Engineering Section, Department of Applied Physics, University of Calcutta, 92, A.P.C. Road, Kolkata 700009, India

¹ Tel.: +91 9830879652, +917003744207

* E-mail: hprasad.mandal@gmail.com

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Abstract: The conventional ultrasonic liquid level measurement techniques are generally based on time of flight (TOF) measurement technique of reflected sound wave from liquid surface in a storage tank. In the present paper, a modified ultrasonic liquid level transducer is developed using the intensity of a 40 kHz ultrasonic pulsating echo signal reflected from the liquid surface as the sensing parameter. A simple transducer circuit converts this pulsating signal into a D.C. voltage signal which is taken as a measure of the intensity of the reflected pulses obtained from the ultrasonic receiver probe. The characteristic equation showing the relation between the transducer output voltage and liquid level is derived in the paper. A proto type unit is developed and tested experimentally to determine the static characteristic of the proposed ultrasonic level transducer. The experimental results are reported in the paper. A nonlinear static characteristic with very good repeatability is observed.

Keywords: Ultrasonic liquid level transducer, Ultrasonic transmitter-receiver probes, Ultrasonic oscillator, Op- amp, Signal conditioner.

1. Introduction

Accurate and reliable measurement of liquid level in a storage tank is very important in any process plant. Among the different techniques [1-3] of liquid level measurement, the direct technique like dip stick, gauge glass, float, displacer etc. and indirect technique like capacitive, inductive, ultrasonic, nucleonic etc. are widely used. The ultrasonic technique has the great advantage that it is a non-contact technique with better longevity, accuracy and linearity. The conventional ultrasonic technique is based on accurate measurement of time of flight (TOF) between the instants of transmitting and receiving of reflected ultrasonic wave

from the liquid surface in a storage tank. But the measuring unit is a complicated microprocessor or microcontroller or computer based system where very accurate measurement of time interval is possible. This time interval is linearly related with the liquid level and the measurement technique is very accurate. Various simplified ultrasonic techniques are still being reported by many research groups.

A. Rocchi, *et al.* [4] have studied in detail, the time of flight technique of measurement of liquid level by using simple ultrasonic sensor. In this study they have analyzed the effects of atmospheric temperature and humidity on the level measurement and have determined the optimum condition of the measuring

system for better accuracy. For accurate measurement of the geometrical and acoustic characteristic parameters of wood and plastic samples from measurement of time of flight,

P. Lasaygues, *et al.* [5] have experimentally applied two coded excitation methods like chirp-coded and wavelet-coded excitation methods. By using two 500 kHz transducers for polyurethane and wood samples, they have shown that the measurement error is 0.13 % minimum in wavelet-coded excitation and 2.3 % maximum in chirp-coded excitation.

A microcontroller based water detection and control system using simple ultrasonic transceiver set has been designed by M. I. Bello, *et al.* [6]. In this technique the water levels of the domestic underground and overhead reservoir tanks have been measured by using time of flight technique.

A non-contact measurement system of liquid petroleum gas (LPG) level in a pressurized LPG tank has been designed and studied by Z. Zakaria, *et al.* [7] using simple ultrasonic sensor mounted above the top surface of the cylinder. In this technique, the ultrasonic wave passes through the cylinder wall and the reflected back from the LPG surface inside the cylinder and the data acquisition system level.

B. Praher, *et al.* [8] have designed an ultrasonic measurement algorithm for the measurement of the thickness of liquid layer between two solid materials using time domain analysis. In this algorithm, the time domain signals received from liquid layer due to multiple reflections are reconstructed to simulate the superimposed signal which is compared with the measured signal to estimate the time of flight of the ultrasonic pulse in a liquid layer and to measure the thickness of the layer.

P. Petlac, *et al.* [9] have applied the commercial of the shelf (COTS) ultrasonic sensors to measure on board aircraft fuel level and quantity. In this measuring system special electronic circuit is designed to develop the high frequency transceiver used in the measurement system.

An accurate time of flight (TOF) measurement technique of ultrasonic echo signal from a liquid surface has been developed by P. Li, *et al.* [10]. In this technique, the exiting ellipse algorithm of TOF measurement is utilized to extract the echo pulse from the ultrasonic echo signal and from the echo pulses a 2D electrical pulse pattern is obtained. The TOF is determined by averaging the two time points of maximum gradients from the elliptical echo pattern.

An accurate dynamic liquid level detection technique is proposed by P. Li, *et al.* [11] using MIMO ultrasonic Transducer array. In this technique the rise and fall of the dynamic liquid level under dynamic condition is detected by applying the virtual element technology on the MIMO ultrasonic level sensor.

M. Suleiman, *et al.* [12] have studied an ultrasonic fluid level measuring system by using the TOF measurement technique. They have studied the proposed measurement system in the range 0.02 m to 4 m with the accuracy of 1 cm.

T. J. Licznarski, *et al.* [13] have proposed an ultrasonic transducer system for accurate measurement of the distance of an object in air. The distance is determined from the measurement of the time interval between the instant of transmitting the signal and the instant of receiving its echo from the object.

Terzic, *et al.* [14] have developed a level measurement system under dynamic condition by using a single ultrasonic sensor and a support vector machine (SVM). In this technique, the measurement error in the raw sensor signal under sloshing effect and temperature variation is minimized by differentiating and smoothing the signal in SVM system.

W. K. Spatt, *et al.* [15] have developed a torsional waveguide in order to measure the liquid depths of different liquid in a mixture. In this technique the time of flight between the incident and reflected wave is found to be a function of liquid level with better sensitivity than the conventional echo technique.

D. W. Lee, *et al.* [16] have proposed a modified ultrasonic method for the measurement of a two phase mixture level. This method is more accurate than the conventional ultrasonic technique to measure liquid level in a two-phase mixture under the high temperature and pressure conditions as well as under the diffused reflection condition from a fluctuated surface of water level. A modified calculation method is developed to determine the correct sound velocity under these conditions and a waveguide is developed to reduce the loss of echo due diffuse reflection and attenuation.

An ultrasonic technique of level measurement has been designed by M. Maribout, *et al.* [17] to measure the level of water and oil in an oil tanker. In this technique, the different acoustic impedances of oil and water in the oil tank produce different signals to the receiver which are correlated with the depths of the liquid in different layers.

A non-invasive technique of level measurement of a liquid in a closed tank under high pressure has been studied by V. E. Sakharov, *et al.* [18] using ultrasonic lamb wave at an optimum frequency of 100 kHz. Here the characteristics of the fundamental and higher order waves passing through the wall of the tank are found to depend on the wall material, wall thickness and the depth of the liquid inside the tank.

E. Vargas, *et al.* [19] have developed an ultrasonic technique for the measurement of liquid level in a closed bottle. In this technique a time of flight measurement method is used from the envelope of echo signal.

An ultrasonic pulse-echo type liquid level measuring technique has been described by A. B. Gillespie, *et al.* [20]. In this technique, the ultrasonic pulse wave travels through a metallic bar or strip towards the liquid surface and the liquid level is estimated from time of flight of reflected echo from a special reflecting structure at the liquid surface.

L. Jakevicius, *et al.* [21] have analyzed the attenuation coefficient of ultrasonic signal in air under isothermal and adiabatic conditions. From this analysis it is shown that the attenuation coefficient of ultrasonic

signal in air is a non-linear function of temperature, relative humidity, pressure and signal frequency.

A microcontroller based ultrasonic distance measurement technique has been studied by S. Y. Yurish [22]. In this time of flight (TOF) technique, the measuring system has been designed by using microcontroller operated ultrasonic smart sensors and universal sensors & transducers interface IC in which the measurement error due to the effect of temperature on sound velocity is eliminated.

In the present paper, an intensity measurement technique of reflected ultrasonic wave from liquid surface in a closed vessel has been studied. The intensity of the echo of ultrasonic wave from the liquid surface is detected and measured by the ultrasonic receiver sensor and the transducer circuit with its output varying non-linearly with the liquid level. The characteristic equation showing the relation between the transducer output and liquid level as well as the liquid surface-receiver probe distance has been derived in the paper. A proto type unit of the proposed level transducer is developed and tested experimentally. The experimental results are reported in the paper. The characteristic graphs obtained from experiment are found to follow the derived equation with better repeatability.

2. Method of Approach

Let an ultrasonic point source of constant power output 'P' is placed at a point 'X' in a free space. Sound waves from this point source moves radially in all directions through the surrounding medium as shown in Fig. 1. If we assume a spherical concentric surface of radius 'R' surrounding the point source then the sound power passing normally through the whole spherical surface of area $A = 4\pi R^2$ is 'P'.

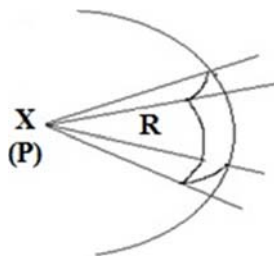


Fig. 1. Propagation of ultrasonic wave from a point source through spherical concentric surface.

So the intensity of sound wave at distance R from an ultrasonic point source is given by

$$I = \frac{P}{A} = \frac{P}{4\pi R^2} \quad (1)$$

Thus the propagation of ultrasonic wave through a medium may be assumed to follow the inverse square

law. Now let us assume that an ultrasonic transmitter-receiver probe set (T_X - R_X) is placed on the cover lid of storage tank as shown in Fig. 2. In the storage tank, the ultrasonic sound wave from the transmitter probe (T_X) moves downwards towards the liquid surface in the storage tank and after reflection from the surface, the reflected echo reaches the receiver probe (R_X). The transmitter probe (T_X) is supplied from a stabilized oscillator circuit to produce an ultrasonic sound wave of constant amplitude and frequency by the transmitter probe. Now in the storage tank, the reflected ultrasonic echo reaching the receiver probe, travels through a distance $d = 2(H - h)$, where 'H' is total height of the storage tank and 'h' is the height of the liquid level inside the tank as shown in Fig. 2. Since the intensity of the ultrasonic sound wave follows inverse square law, so the intensity (I_r) of echo in receiver (R_X) of storage tank may be given by,

$$I_r \propto \frac{1}{d^2} \quad \text{or, } I_r = \frac{K_1}{d^2} = \frac{K_1}{4(H - h)^2}, \quad (2)$$

where K_1 is the constant of proportionality.

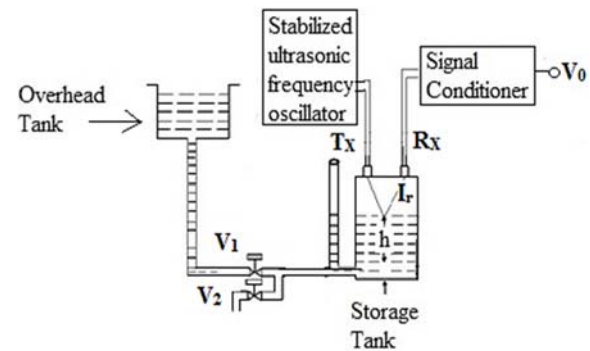


Fig. 2. Schematic diagram of the experimental set-up for the proposed ultrasonic level transducer.

Since the output of the receiver probe is directly proportional to the intensity of the received sound, so the a.c. output (V_1) of the receiver probe may be given by,

$$V_1 \propto I_r \quad \text{or, } V_1 = K_2 I_r = \frac{K_1 K_2}{4(H - h)^2}, \quad (3)$$

where K_2 is the constant of proportionality.

The transducer circuit in the form a signal conditioner circuit as shown in Fig. 2 converts the above a.c. signal output of receiver probe into an amplified dc signal output.

2.1. Measuring Circuit

The measuring circuit designed in the proposed liquid level measuring system consists of a stabilized ultrasonic oscillator circuit supplying the excitation

signal as shown in Fig. 3 and an ultrasonic transmitter probe with its output connected with a signal conditioner or transducer circuit as shown in Fig. 4.

In Fig. 3, the ultrasonic transmitter probe (T_x) is supplied from a stabilized IC555 timer-based oscillator with 50 % duty cycle. The oscillator is designed from an astable multivibrator using the timer IC555 supplied from a stabilized DC source. From the data manual of IC 555 timer circuit, the frequency of oscillation is given by

$$f = \frac{1.44}{(R_A + 2R_B)C} \quad (4)$$

and its duty cycle is given by

$$D = \frac{R_B}{(R_A + 2R_B)} \times 100\% \quad (5)$$

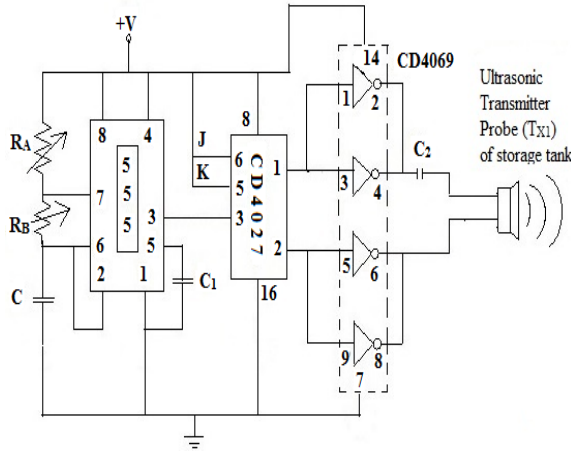


Fig. 3. Ultrasonic transmitter probe supplied from a stabilized oscillator circuit.

In the proposed ultrasonic transmitter circuit as shown in Fig. 3, the frequency of the IC555 timer oscillator is selected at 80 kHz. From this 80 kHz output signal of the timer circuit, two 40 kHz signals with opposite phases are developed by using short circuited JK flip flop IC CD4027. These two signals are used to excite the transmitter probe (T_x) through a buffer stage IC (4069) to produce 40 kHz ultrasonic signal. Since the transmitter probe is mounted on the cover lid of the tank with its transmitting surface facing towards the bottom of the tank, so the ultrasonic wave produced by the transmitter probe in the storage tank propagates towards the liquid surface of the storage tank and after reflection from the liquid surface, the reflected sound wave or echo sound reaches the ultrasonic receiver probe mounted on the same cover lid as shown in Fig. 2. In Fig. 4, the signal conditioner circuit acting as the transducer unit converts the input echo signal received by the receiver probe (R_x) into the dc output voltage signal V_0 . The signal conditioner circuit consists of the non-inverting amplifier circuit with op-amp A_1 , a precision half wave rectifier with

op-amp A_2 and zero adjustment circuit with op-amp A_3 . The a.c output signal of the non-inverting amplifier circuit is given by,

$$V_2 = \left(1 + \frac{R_2}{R_1}\right) V_1 = \left(1 + \frac{R_2}{R_1}\right) \frac{K_1 K_2}{4(H-h)^2} \quad (6)$$

The rectified d.c. output of the precision rectifier circuit with op-amp A_2 is directly proportional to the a.c input signal V_2 . So the d.c. output V_3 is given by,

$$\begin{aligned} V_3 &\propto V_2 \\ \text{or, } V_3 &= K_3 V_2 = \left(1 + \frac{R_2}{R_1}\right) \frac{K_1 K_2 K_3}{4(H-h)^2} \quad (7) \\ \text{or, } V_3 &= \frac{K_4}{(H-h)^2} \end{aligned}$$

where K_3 is the constant of proportionality

$$\text{and } K_4 = \frac{K_1 K_2 K_3}{4} \left(1 + \frac{R_2}{R_1}\right) \quad (8)$$

The output (V_0) of the unity gain differential amplifier circuit using op-amp A_3 is given by

$$V_0 = V_3 - V_Z = \frac{K_4}{(H-h)^2} - V_Z \quad (9)$$

$$\text{or, } V_0 = \frac{K_4}{d^2} - V_Z \quad (10)$$

where $d = H - h$ is the distance between the reflecting surface of the liquid and the ultrasonic transceiver probes placed on storage tank cover lid and V_Z is the zero adjustment voltage input of the unity gain differential amplifier using op-amp A_3 . For $V_Z = 0$,

$$V_0 = \frac{K_4}{d^2} \quad (11)$$

Hence the transducer output V_0 decreases with the increase of the distance between the reflecting surface of the liquid and the transceiver probes, i.e., the transducer output decreases non-linearly with the increase of liquid level. In equation (9) and (10), the sensitivity constant K_4 can be adjusted by varying the gain potentiometer R_2 as shown in equation (8). The zero adjustment voltage V_Z is selected in order to obtain a desired minimum value of the transducer output at zero value of liquid level or at maximum value of liquid surface-receiver probe distance. With the increase of level, the liquid surface-receiver probe distance (d) decreases and the transducer output (V_0) increases as the equation (10). Thus the maximum and minimum values of the transducer output at maximum and minimum values of liquid level respectively are adjusted by varying the gain potentiometer R_2 and the zero adjustment potentiometer R_Z as shown in Fig. 4.

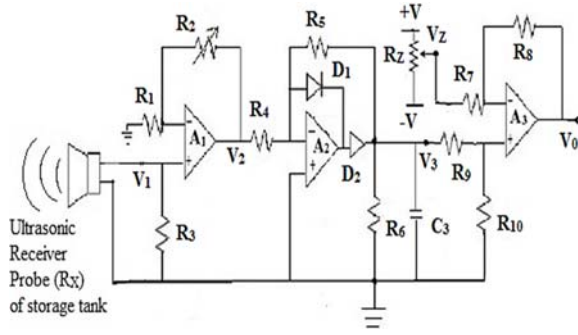


Fig. 4. Ultrasonic receiver probe and transducer circuit.

2.2. Error Calculation in Pulse to DC Signal Conversion Process (by Half Wave Precision Rectifier Circuit with Op-amp A₂)

The amplified pulse signal (V_2) is converted into smooth DC signal with the help of the precision half wave rectifier circuit consisting of op-amp A₂ as shown in Fig. 4 and the capacitive filter C₃ with load resistance R₆. An error signal is produced in this conversion process which may consist of two parts: error due to noise and error due to ripples.

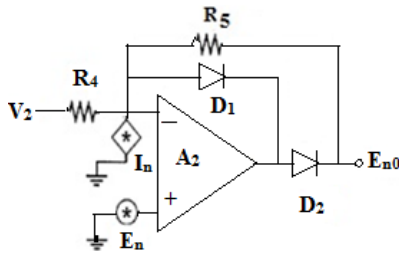


Fig. 4 (a). Noise equivalent of half wave precision rectifier.

From the noise equivalent circuit of the half wave precision rectifier as shown in Fig. 4 (a), the output noise voltage E_{n0} per unit frequency bandwidth can be calculated from the following equation (12).

$$E_{n0}^2 = \left(1 + \frac{R_5}{R_4}\right)^2 E_n^2 + I_n^2 R_5^2 + 4\pi k_B T \left(\frac{R_4 R_5}{R_4} + R_5\right), \quad (12)$$

where k_B is the Boltzmann constant (1.38×10^{-23} J/K) and T is the absolute temperature.

From the manufacturer's datasheet of the selected op-amp (OP07),

$$E_n = 9.6 \times 10^{-9} \text{ V} / \sqrt{\text{Hz}} \text{ and } I_n = 14 \times 10^{-12} \text{ A} / \sqrt{\text{Hz}}$$

Putting these values in (12), we have the output noise voltage for $R_4 = R_5 = 1 \text{ k}\Omega$ and $T = 300 \text{ K}$ given by

$$E_{n0} = 2.59 \times 10^{-8} \text{ V} / \sqrt{\text{Hz}} \quad (13)$$

Hence the error due to noise may assume to be negligible.

The error due to ripples may be estimated from the calculation of the ripple factor of the capacitive filter C₃ with R₆ acting as load shown in Fig. 4. As per the proposed design, the pulse frequency $f = 40 \text{ kHz}$ = ripple frequency, $R_6 = 1 \text{ k}\Omega$ and $C_3 = 220 \text{ }\mu\text{F}$. Hence the ripple factor (r_f) is given by

$$r_f = \frac{1}{2\sqrt{3} f R_6 C_3} = 3.28 \times 10^{-5}$$

Thus the ripple factor in the proposed design is negligible and the additional error introduced in the pulsating signal to DC signal conversion process due to the ripples may also be assumed negligible.

3. Design

The proposed ultrasonic level transducer system is designed by selecting the ultrasonic transmitter and receiver probe units as 40TR-12W, which is commercially available in the market as discrete transmitter and receiver probes. The storage tank which is selected in proposed design is a cylindrical plastic tank of internal height 38 cm and outer diameter 20 cm with a lid cover on which ultrasonic transmitter and receiver probes are mounted by using an adhesive compound like fevi-quick with their sensing surfaces facing towards the liquid surface inside the storage tank. The storage tank is attached with a gauge glass marked with mm scale from which the liquid level inside the storage tank can be measured. Now the excitation circuit of the transmitter sensor is designed for 80 kHz using IC 555 timer based a stable multivibrator circuit as shown in Fig. 3. For 50 % duty cycle, $50 = \frac{R_B}{(R_A + 2R_B)} \times 100$ or $R_A = 0$.

Hence for designing 80 kHz oscillator, we select $C = 1 \text{ nf}$. So from equation (4), we get

$$80000 = \frac{1.44}{(R_A + 2R_B)C} = \frac{1.44}{(R_A + 2R_B)10^{-9}} \text{ or, } R_A + 2R_B = 18000$$

Since for 50 % duty cycle $R_A = 0$, so $R_B = 9000 \Omega = 9 \text{ k}\Omega$. In Practical circuit, the duty cycle may be selected slightly less than 50 %. So R_A is selected as variable $1 \text{ k}\Omega$ metal film 1 Watt potentiometer and R_B is selected as variable $10 \text{ k}\Omega$ metal film 1 Watt potentiometer. By adjusting the values of these potentiometers, 80 kHz pulsating signal is produced. The short circuited JK Flip-flop IC CD4027 divides this frequency by two and produces two 40 kHz signals of opposite phases at the output terminals. These 40 kHz signals are used to excite the transmitter probe (T_x) of storage tank through the buffer IC (CD4069) and capacitor C₂ which is selected

as 220 μf in order to block any d.c part present in the excitation signal.

The receiver circuit is designed by selecting the gain of the non-inverting amplifier using op-amp A_1 is selected at 20. So we have the gain equation,

$$20 = 1 + \frac{R_2}{R_1} \text{ or, } R_2 = 19R_1$$

Now R_1 is selected as 1 k Ω metal film half watt resistance with 1 % tolerance. Hence $R_2 = 19 \text{ k}\Omega$. So R_2 is selected as 22 k Ω metal film 1 Watt potentiometer with 5 % tolerance. For unity gain differential amplifier circuit with op-amp A_3 , $R_7 = R_8 = R_9 = R_{10}$ and each is selected as 1 k Ω metal film half watt resistance with 1 % tolerance. The other resistors $R_3 - R_6$ are also selected as 1 k Ω metal film half watt resistances each with 1 % tolerance. The zero adjustment potentiometer R_Z is selected as 22 k Ω , 1 Watt, and metal film linear potentiometers with 5 % tolerance. The op-amps A_1 , A_2 and A_3 are selected as low noise op-amp ICs OP-07. The diodes D_1 & D_2 are selected as IN 4148.

3.1. Accuracy Analysis

The accuracy of a transducer or any measuring unit may be determined from the measured output obtained by the repetition of the experiment for several times for the same input under the same environment in both increasing and decreasing modes as per IEC 61298-2 standard [2, 18]. From the repeated measured data, it is obtained from the zero deviation line or best-fit characteristic curve expressed in percentage of span or maximum range from the following equations.

$$\text{Measured accuracy} = \pm \frac{\text{Maximum (Best fit data-Measured data)}}{\text{Span}} \times 100\% \quad (14)$$

$$\begin{aligned} \text{Hysteresis plus dead band} \\ = \pm \left[\frac{\text{Maximum}[(\text{Measured data in increasing mode} - \text{Measured data in decreasing mode}) \text{ for the same input in one cycle}]}{\text{span}} \right] \times 100\% \end{aligned} \quad (15)$$

$$\text{Accuracy} = \pm \left(\frac{\text{Measured accuracy} + \text{hysteresis plus dead band}}{\text{span}} \right) \quad (16)$$

4. Experiment

The experiment was performed by using the experimental set up as schematically shown in Fig. 2 with its photographic view shown in Fig. 5. The proposed level transducer unit as shown in Fig. 2 and Fig. 5 consists of a storage tank provided with a gauge glass, an inlet valve V_1 and an outlet valve V_2 .

This tank may be filled up with tap water from an overhead tank through the inlet valve V_1 and may be

emptied through the outlet valve V_2 . The level of water in the tank at steady state can be measured from the position of water surface along the millimetre scale attached with the gauge glass.

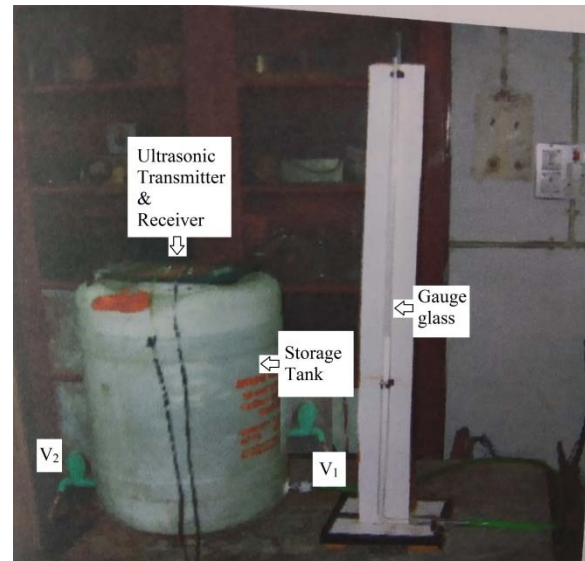


Fig. 5. Photographic view of the experimental set up.

To determine the static characteristic of the transducer, a particular level in the storage tank was selected as the datum level and by alternately opening and closing the inlet valve V_1 , the liquid level in the tank above the datum level was increased in steps and at each step the value of the transducer output was measured by a four and half digit multimeter and the corresponding liquid level above datum position was measured from the difference between the readings of the liquid surface position and the datum position along the gauge glass. From this value of level, the distance between the liquid surface and the receiver probe fixed on the cover plate was also determined from the difference between the maximum tank height and the reading of the liquid surface position along the gauge glass. Similarly by opening and closing of the exhaust valve V_2 , the liquid level was decreased in steps and at each step, the values of the transducer output, the liquid level and the distance between the liquid surface and the receiver probe were measured during performing the experiment in decreasing mode. The experiment was repeated for ten times in both increasing and decreasing modes at different dates and times under the same environment of an air-conditioned laboratory maintained at 25 $^{\circ}\text{C}$. Now the static characteristic curves of the proposed transducer were drawn by plotting the transducer output against the distance between the liquid surface and receiver probe as shown in Fig. 6 (a). From these measured values of transducer output at a given level and at a given liquid surface-receiver probe distance, obtained during ten repetitions under the same laboratory environment, the average value of these transducer outputs was determined. Now the average static

characteristic curve of the transducer was drawn by plotting the average transducer output against the liquid surface-receiver probe distance as shown in Fig. 6(b). From this average static characteristic curve the best fit curve is drawn using Microsoft excel program along with the best fit characteristic equation as shown in the same figure. The percentage deviation of each measured average value from the best fit value is now determined and the percentage deviation curve of the transducer is drawn as shown in Fig. 6(c). Now at each level and liquid surface-receiver distance, the standard deviation (σ) of the measured data obtained in

ten repetitions is determined by using Microsoft Excel program. For each value of standard deviation, the percentage repeatability (r) of the measured data is determined by using the standard ASTM formula [18] given by, $r = 2\sqrt{2} \frac{\sigma}{\bar{X}_{\max}} \times 100\%$ where, $\bar{X}_{\max}$ is the

maximum average value for the transducer output. The repeatability curves for the proposed level transducer is now drawn by plotting the repeatability against the liquid surface-receiver probe distance as shown in Fig. 6(d).

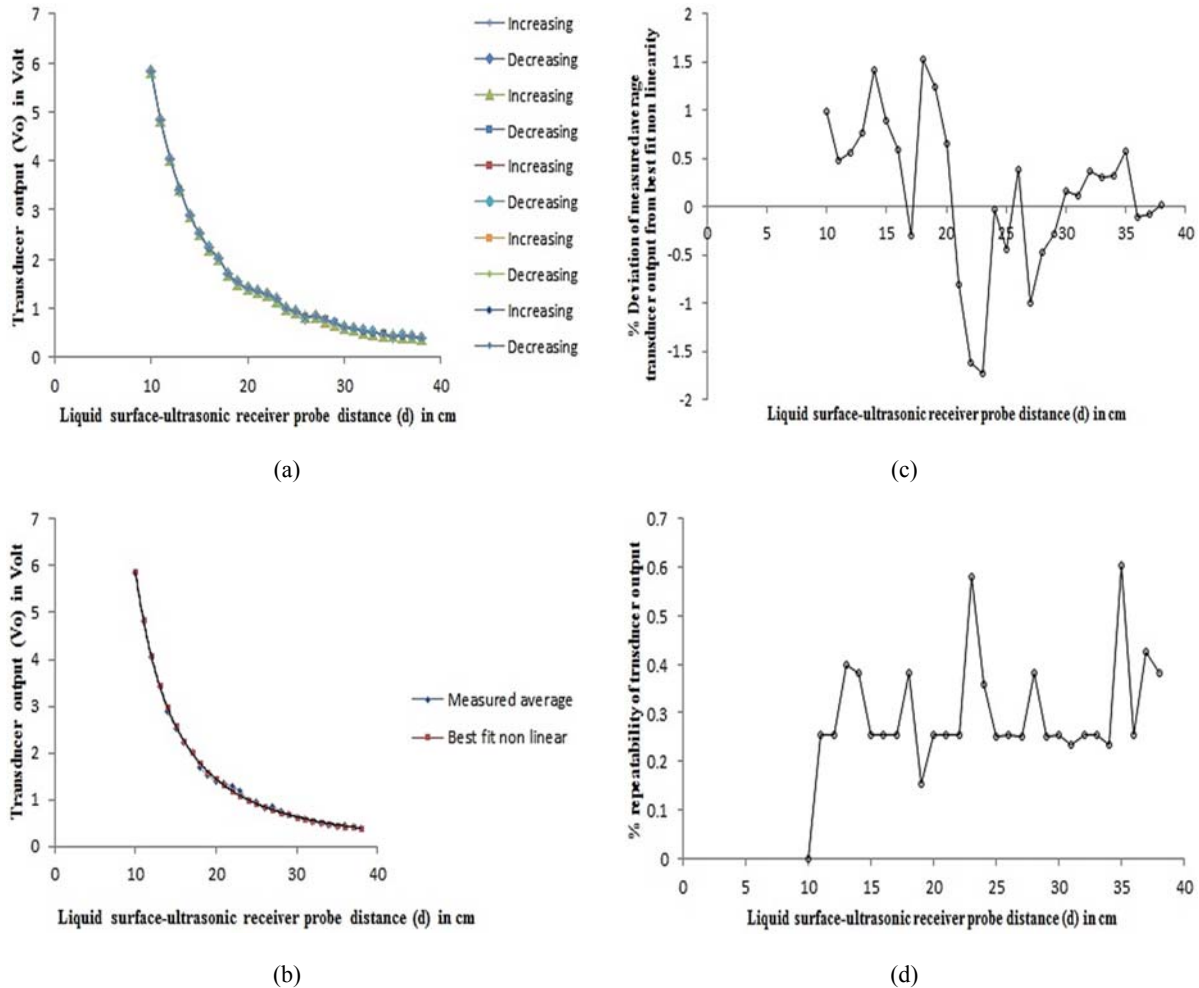


Fig. 6. Static characteristic curves of the proposed transducer with respect to the distance of reflecting water surface from the ultrasonic transmitter:

- Static characteristic curves of the proposed transducer for the measured data obtained from ten repetition in increasing and decreasing modes;
- Average static characteristic curve of the proposed transducer along with best fit characteristic and best-fit characteristic equation;
- Percentage deviation of the measured average static characteristic data from the corresponding best-fit data;
- Percentage repeatability of the measured data observed in ten repetitions.

5. Conclusions

The transducer static characteristic curves of the transducer obtained in ten repetitions of the experiment under the same laboratory environment at different dates and times as shown in Fig. 6(a) are all found to

be almost similar to the average static characteristic curve as shown in Fig. 6(b). The best fit characteristic equation as shown in Fig. 6(b) follows the derived equation (11) to a very good extent. The percentage deviation from the best fit non-linearity is also found to be very small as shown in Fig. 6(c). From the

percentage repeatability curve of the proposed level transducer as shown in Fig. 6 (d), the transducer is found to have good repeatability.

In the conventional non-contact ultrasonic liquid level transducer, the time of flight (TOF) between the instants of transmitting and receiving of the reflected ultrasonic wave from liquid surface of a storage tank is measured by a microprocessor or microcontroller or computer based technique. So the measuring unit is very costly but due to its various advantages such as very good linearity and good measurement accuracy, it is widely used in industry. But the proposed transducer technique is a simple intensity sensing technique and does not require any of the digital system associated with the conventional TOF technique. So the proposed level transducer technique involves much less cost than the conventional measuring unit. Its main disadvantage is that its output static characteristic is nonlinear. But this disadvantage can be easily overcome by using simple analog or digital linearization technique.

The measured accuracy, hysteresis plus dead band and overall accuracy of the proposed level transducer are calculated from the measured data in the repeated experiments under the same laboratory environment by using the standard equations (12), (13) and (14) respectively and are respectively, found to be $\pm 1.85\%$, $\pm 0.184\%$ and $\pm 2.034\%$. Thus the accuracy of measurement using the proposed level transducer is comparably good with respect to the conventional techniques as shown in Table 1.

Table 1. Comparative study of the measurement accuracy of the proposed level transducer with the conventional level transducers [2].

Type of transducer	Accuracy in $\pm$ % of span	Inference
Air bubbler type	0.5-1	The measurement accuracy of the proposed modified transducer is comparable with that of the conventional transducers
Capacitance type	0.5-3	
Diaphragm type	1-3	
Differential pressure type	0.25-1	
Displacer type	0.25-1	
Float type	0.1-3	
Radar type	0.1-1	
Nuclear type	1-2	
Resistance type	0.1-1	
Ultrasonic type	0.25-3	
Proposed modified ultrasonic type	2.034	

A good resolution of 1 mm was observed in the proposed flow transducer experiment because the level was measured from an mm scale. However, the proposed transducer was also found to respond to a very small change of level less than 1 mm. In industrial environment, an accuracy of 2.034 % of the liquid level measurement system is within acceptable limit and is comparable with the accuracy of some other techniques which may be as high as 3 %. The lack in

accuracy of the proposed technique may be due to the effect of atmospheric parameters like temperature, humidity etc. on the intensity of the ultrasonic signal. So a study of this effect is left as a future scope of the present work.

The conventional TOF type ultrasonic transducer output is dependent on the atmospheric parameters like temperature, humidity, etc. because for the liquid surface-receiver probe distance ($d = H-h$), $TOF = d / V = (H-h)/V$ is linearly dependent on level (h) only when the velocity (V) of sound wave is constant. Since the velocity of sound wave depends on these atmospheric parameters, the conventional ultrasonic flow transducer may suffer from measurement error. Now the intensity of sound wave is primarily dependent on the propagation distance along with the atmospheric parameters. But for a limited value of level in a storage tank, the effect of atmospheric parameters on the intensity of sound wave may be assumed to be negligible. Hence the error in level measurement by using the proposed technique due to the atmospheric parameters may be assumed to be smaller than that observed in the conventional technique.

It may be mentioned here that in the modern electronic era, the TOF type microcontroller based level or distance transducer IC like USTI, UFDC-1, UFDC-1M etc. are now easily available in the market at small cost. One disadvantage of this system may be mentioned as that it is not repairable. So in the present paper a simple low cost intensity sensing type technique has been proposed, which is repairable. The decrease of reliability due to use of more number of ICs may be overcome by selecting low noise op-amps like OP-07. In the proposed technique the effect of atmospheric temperature on the sound intensity has been ignored because the experiments have been performed repeatedly under the same environment of an air-conditioned laboratory maintained at 25 °C throughout a year. Since the air column collected over the liquid inside a storage tank is always saturated with the liquid vapor, so in the present work, the effect of humidity on sound intensity has not been considered. However, in industrial application, the effects of these atmospheric parameters as well as the signal frequency should be studied. This is left as a future scope of the present work.

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References

- [1]. Fraden J., Handbook of Modern Sensor, 3rd edition, AIP Press, Springer, 2003.

- [2]. Liptak B. G., Process Measurement and Analysis, 3rd edition, *Butterworth Heinman Ltd*, 1999.
- [3]. Considine D. M., Process Instruments and Controls Handbook, 2nd edition, *McGraw-Hill*, New York, NY, USA, 1999.
- [4]. Rocchi A., Santeccchia E., Ciciulla F., Mengucci P., Barucca G., Characterization and optimization of level measurement by an ultrasonic sensor system, *IEEE Sensors Journal*, Vol. 19, Issue 8, April 2019, pp. 3077-3084.
- [5]. Lasaygues P., Arciniegas A., Espinosa L., Prieto F., Brancheriau L., Accuracy of coded excitation methods for measuring of time of flight: Application to ultrasonic characterization of wood samples, *Ultrasonics*, Elsevier, Vol. 89, September 2018, pp. 178-186.
- [6]. Bello M. I., Gana S. M., Faruk M. I., Umar M. J., Autonomous ultrasonic based water level detection and control system, *Nigerian Journal of Technology (NIJOTECH)*, Vol. 37, June 2018, pp. 808-513.
- [7]. Zakaria Z., Idroas M., Samsuri A., Adam A., Ultrasonic instrumentation system for liquefied petroleum gas level monitoring, *Journal of Natural Gas Science and Engineering*, Elsevier Science Direct, Vol. 45, September 2017, pp. 428-435.
- [8]. Praher B., Steinbichler G., Ultrasound based measurement of liquid layer thickness: a novel time domain approach, *Mechanical Systems and Signal Processing*, Elsevier Science Direct, Vol. 82, January 2017, pp. 166-177.
- [9]. Petlach P., Dub M., Some aspects of COTS ultrasonic fuel level measurement, in *Proceedings of the IEEE International Conference on Military Technologies*, June, 2017, pp. 578-581.
- [10]. Li P., Chen S., Cai Y., Chen J., Li J., Accurate TOF measurement of ultrasonic signal echo from the liquid level based on a 2-D image processing method, *Neurocomputing*, Elsevier Science Direct, Vol. 175, January 2016, pp. 47-54.
- [11]. Li P., Cai Y., Chen X., Nabuzaale S., Yin J., Li J., An accurate detection for dynamic liquid level based on MIMO ultrasonic transducer array, *IEEE Transactions on Instrumentation and Measurement*, Vol. 64, Issue 3, March 2015, pp. 582-594.
- [12]. Suleiman M., Saidu G. I., Ilyasu M. I., Adeboye A. O., Hamza M., Ultrasonic fluid level measuring device, *International Journal of Recent Development in Engineering and Technology (IJRDET)*, Vol. 4, 2015, pp. 1-5.
- [13]. Licznarski T. J., Jaroński J., Kosz D., Ultrasonic system for accurate distance measurement in the air, *Ultrasonics*, Elsevier, Vol. 51, Issue 8, December 2011, pp. 960-965.
- [14]. Terzic J., Nagarajah C. R., Alamgir M., Fluid level measurement in dynamic environments using a single ultrasonic sensor and support vector machine, *Sensors and Actuators*, Elsevier Science Direct, Vol. 161, Issue 1-2, June 2010, pp. 278-287.
- [15]. Spatt W. K., Vetelino J. F., Lynnworth L. C., Liquid level torsional ultrasonic waveguide sensor, *IEEE International Ultrasonics Symposium Proceeding*, October 2009, pp. 663-668.
- [16]. Lee D. W., No H. C., Song C. H., Measurement of two-phase mixture level using an ultrasonic method, *Experimental Thermal and Fluid Science*, Elsevier, Vol. 29, Issue 5, June 2005, pp. 609-614.
- [17]. Maribout M., Habli M., Naamany A. A., Busaidi K. A., A new ultrasonic based device for accurate measurement of oil, emulsion, and water levels in oil tanks, in *Proceedings of the IEEE International and Measurement Technology Conference*, Vol. 3, May 2004, pp. 1942-1947.
- [18]. Sakharov V. E., S. A. Kuznetsov, S. A., Zaitsev B. D., Kuznetsova I. E., Joshi S. G., Liquid level sensor using ultrasonic lamb waves, *Ultrasonic*, Elsevier Science Direct, Vol. 41, Issue 4, June 2003, pp. 319-322.
- [19]. Vargas E., Ceres R., Marti'n J. M., Caldero'n L., Ultrasonic sensor for liquid level inspection in bottles, *Sensors and Actuators Elsevier Science Direct*, Vol. 61, Issue 1-3, June 1997, pp. 256-259.
- [20]. Gillespie A. B., Deighton M. O., Pike R. B., R. D. Watkins, A new ultrasonic technique for the measurement of liquid level, *Ultrasonics*, Elsevier, Vol. 20, Issue 1, January 1982, pp. 13-17.
- [21]. Jakevicius L., Demcenko A., Mardosaite R., Ultrasound attenuation dependence on air compression or expansion processes, *Ultragarsas (Ultrasound)*, Vol. 65, Issue 1, 2010, pp. 42-46.
- [22]. Yurish S. Y., Distance Measurement System Based on Ultrasonic Smart Sensors and Universal, Sensors and Transducers Interface (USTI), *Sensors and Transducers*, Vol. 243, Issue 4, August 2020, pp. 24-30.

