Analysis of common errors and methods of calibration of ultrasonic level meter

A. A. Yusupov[1*], *U. K.* Sabirov[1], *M. Sh.* Begijonov[1], and *D. H.* Valiyev[1]

[1]Andijan Machine-Building Institute, Andijan, Uzbekistan

Abstract. This article is devoted to improve the accuracy of the measuring system to the analyzing of common errors of an ultrasonic level meter designed to measure the level of liquid materials in tanks. To reduce the random error of the measurement system, appropriate measures and compensation methods are presented. As a result, it was revealed that the generalized cumulative error of the device belongs to the interval G = 1.3 - 2%.

1 Introduction

With the accelerated development of modern industrial production, ultrasonic level gauges are increasingly being used and have become widely used in various tanks and reservoirs, as well as reservoirs, rivers and canals, as an important inspection and control method for measuring liquid levels in industrial production. Regardless of where it is used, the accuracy of the measurement of a level gauge is becoming ever more demanding. This article reviews and extensively analyzes the more common errors that can occur when measuring ultrasonic level gauges, and suggests appropriate measures and methods for compensating.

Level measurement - is the determination of the height of the working medium in a technological apparatus filled with liquid or granular substances. The measuring device for this task is called a level gauge [1, 2].

Among the many methods for measuring the level of liquid and bulk materials, ultrasonic level gauges are simple and easy to use [3-5], and they are suitable for almost any liquid, including aggressive and explosive ones; allow operation in a wide range of temperatures and at high pressures, vibration and shock loads; have high reliability, non-failure operation in a long period of time and sufficiently high accuracy. Today, there are many types of ultrasonic level gauges on the market, which have different characteristics and parameters.

Ultrasonic level gauges are widely used in many manufacturing processes to measure the level of liquids. However, some measured media are hazardous materials such as toxic, corrosive, flammable and even explosive, with a wide temperature and pressure range and variable media characteristics such as steam, dust, foam, turbulence and condensate. All these factors, often in combination with each other, make it extremely difficult to accurately and reliably measure the level [6].

* Corresponding author: azamat7uzbek@gmail.com

Ultrasonic level gauges have similar but different limitations. The acoustic pulse or sound wave emitted by the device travels through the air until it hits the surface of the liquid or bulk material in the tank or the tank wall (Fig. 1). The strength of the reflected signal depends on the bulk density of the material, which is the mass of the substance in a given volume. Therefore, if the surface of the material remains fluffy, it absorbs some of the sound energy and the reflected waves are not as strong.

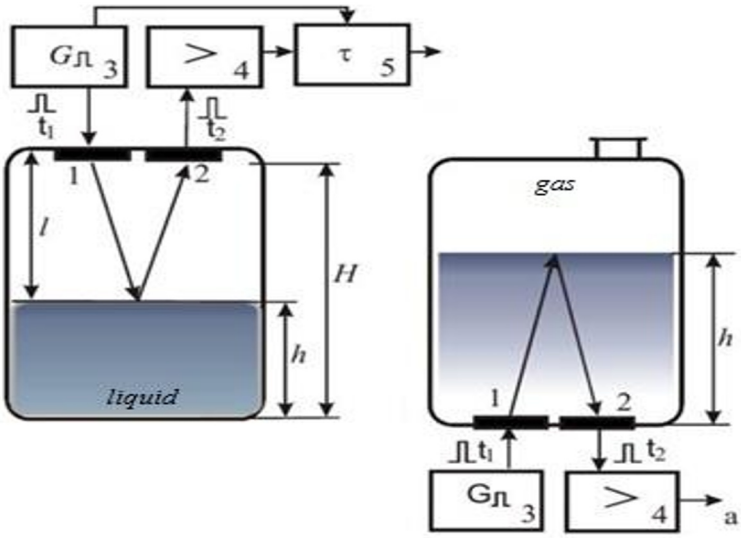

Fig. 1. Methods for placing an ultrasonic level gauge in the measurement process. (1,2 - signal transmitter and receiver, 3 - signal generator, 4 - received signal amplifier, 5 - signal processing).

Although the situations in which it can cause a serious problem are rare, especially chemical products. Since the beam is much wider than non-contact radar level gauges, the instrument can collect information to calculate the average level over the entire visible surface. For some tanks, level information may be sufficient to calculate volume to within 3% accuracy, but for larger tanks, multiple tools may be required to obtain such results.

2 Research methods and results

Based on the analysis of literary sources, it is possible to list the existing influencing factors on the measurement accuracy of an ultrasonic level gauge:

1. The error of the reference speed of sound.

According to the ratio between the distance value L, the speed of sound c and the transmission time t, L = vt/2, it can be seen that the transmission time of the ultrasonic wave is an intermediate result of measuring the liquid level. When using an ultrasonic level gauge to measure the liquid level, it is necessary to know the speed of propagation of ultrasonic waves in the air, so the accuracy of the speed of propagation of ultrasound will greatly affect the accuracy of the measurement of the ultrasonic level gauge.

2. Temperature compensation.

Generally speaking, temperature is the main factor affecting the speed of sound. The ratio between the speed of sound in air and air temperature is v=331.5+0.6t m/s. It can be seen from the temperature compensation formula for this speed of sound that the speed of sound depends strongly on temperature.

In air, a temperature difference of 1°C affects the speed of sound of 0.6 m/s. At 20°C standard atmospheric pressure, the speed of sound is about 344 m/s, so it can be seen that the influence on the measurement error is about 0.17%. liquid level exceeds 0.5%. The ambient temperature should be measured to correct the speed of sound. By attaching a temperature sensor to an ultrasonic level transmitter, the temperature can be measured in real time, and the sound velocity value can be converted using the relationship between temperature and sound velocity. However, in reality, the speed of sound depends not only on temperature, but is also related to many factors such as gas density, air pressure, humidity, suspended solids in the air, etc. Therefore, in practical applications, there are still many shortcomings in sound speed calibration only temperature measurement method, and there are certain errors in the temperature measurement process. The temperature compensation method is only suitable for general applications and cannot meet the requirements of high precision measurement.

In practical applications, we must choose an ultrasonic level transmitter with a temperature compensation function to compensate for the effect of ambient temperature changes on liquid level measurement.

3. Real-time sound speed compensation.

Practice has proven that due to the complexity of the measurement environment and measurement methods, it is necessary to introduce new errors, regardless of what empirical formulas and data are used to compensate for the speed of sound. Therefore, compensation for the speed of sound by measuring it is considered a reliable method of compensation.

A partition is installed at the front end of the transmitting probe, forming a fixed interval of the sound path with the probe (Fig. 2). This structure is called the sound path frame. When the probe emits sound waves, the partition can reflect some of the sound waves back to the probe. After the probe receives the reflected wave, it calculates the time from radiation to reception and calculates the speed of sound.

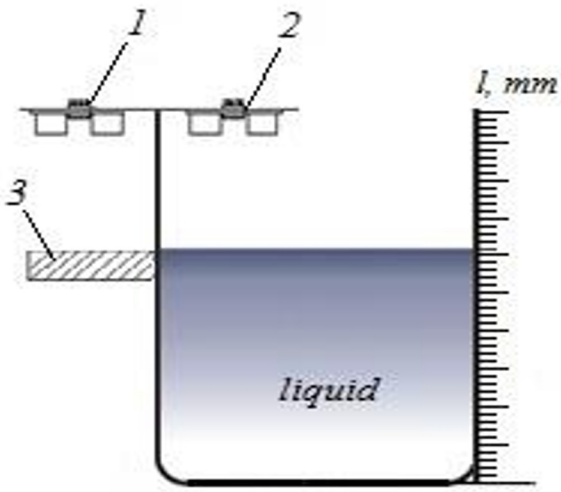

Fig. 2. The method of installing a standard partition when measuring the level with two sensors (1, 2); 3 – partition.

To compensate, the method of measuring the speed of sound is used. Since the compensated speed of sound is very similar to the medium in which the measured path of sound propagation is located, and the influence of the environment is basically the same, the speed of sound is usually relatively close, so this method is a more accurate method of correcting the speed of sound currently used. Although this method reduces computational

complexity, eliminates useless ultrasonic waves and improves measurement accuracy, the cost of two transducers is relatively high, which does not contribute to popularization.

Wave equation of ultrasound propagation in air:

$$\mathrm{A}(x,t) = A(x)\cos\left(wt - \frac{2\pi}{\lambda}x\right) = A_0 e^{-2ax}\cos\left(wt - \frac{2\pi}{\lambda}x\right) \quad (1)$$

where, A - is the amplitude obtained by the ultrasonic transducer, A_0 - is the initial amplitude emitted by the ultrasonic transducer, x - is the propagation distance of the ultrasonic signal, ω - is the angular frequency of the ultrasonic signal, t - is the propagation time of the ultrasonic signal, λ - is the ultrasonic wavelength, α - is the attenuation coefficient ultrasound, and its formula: $\alpha = bf_2$, where b - is the permittivity and f -is the ultrasound frequency.

However, when using this method, the sound path frame housing must be made of a material with a low thermal expansion coefficient to prevent the sound path frame from expanding when heated and shrinking when cold due to changes in ambient temperature, which can change the sound path distance and affect the accuracy of measuring the speed of sound.

4. Transmission timing error.

A sound wave is a longitudinally oscillating elastic mechanical wave that propagates due to the molecular motion of the propagating medium. Due to the absorption, scattering and diffusion of the sound wave in the propagation medium, the sound intensity, sound pressure and sound energy weaken, and the sound wave weakens. In addition, when measuring with an ultrasonic level gauge, it is necessary to form a reflection of the sound wave on the surface of the liquid being measured, which will also cause the attenuation of the sound wave. Sound waves decay exponentially depending on the distance they travel. When the liquid level is different, the propagation distance of the sound wave is also different, and the amplitude of the received wave is also very different. When the probe emits ultrasonic waves, the system starts counting time, and when the amplitude of the received signal exceeds the set threshold, the system stops counting time. When the liquid level changes, the amplitude of the received signal also changes.

When the liquid level is low, the amplitude of the received signal is small and it may be necessary to reach the threshold at the fourth peak; when the liquid level is high, the amplitude of the received signal is large and may reach the threshold at the third peak or earlier.

Thus, the time of stopping the countdown is uncertain, and this uncertainty will inevitably lead to errors in the accuracy of the measurement of the system. If this error is applied to oil storage tanks above 10 meters, it will lead to very objective errors, so it needs to be eliminated.

Currently, a simple way to eliminate the transit time error is to add a time control circuit (TCC), which can compensate for the attenuation of the sound wave during propagation, so that the amplitude of the received wave is basically the same at different fluid levels to minimize measurement errors. However, this method still has significant limitations.

In this method, it is necessary to predict the propagation time of sound waves at different heights of the liquid level and the attenuation of sound waves at this distance, and then construct a curve corresponding to the relationship between them and design a time gain control scheme that corresponds to the equation of the curve.

According to the previous analysis, propagation time and attenuation are two important factors that are easily influenced by the scene environment and that cannot be well matched with a pre-prepared curve. In addition, even if the fitted curve is very accurate, it is difficult to design a TCC circuit that would be completely consistent with it. Therefore, it is inevitable that new errors will be introduced into the compensation.

In order to eliminate the transit time error, the signal conversion process of the receiving circuit consists in preprocessing the received signal, extracting the envelope of the signal after DC detection and differentiating the envelope.

In the process of signal conversion, regardless of the amplitude of the received signal, the peak value of its envelope should be in the middle of the time of the received signal, that is, at the zero intersection point of the differential signal. Therefore, the stop synchronization signal generated by the zero crossing detection circuit must be in the middle of the echo signal time and will not change due to the amplitude of the signal, thereby completely eliminating the time-of-flight error.

5. System error.

System error is mainly caused by system delay, and system delay is mainly due to hardware circuit delay, single-chip microcomputer interrupt response delay, and sensor response delay. Since the ultrasonic level transmitter operates in pulsed emission mode, each time the microcontroller sends a emission command, the transmit power amplifier circuit must go through an energy storage process to reach the emission state. At the same time, the piezoelectric ceramics in the probe also have a vibration triggering process that takes a certain time to reach the vibration frequency of 40 kHz. However, the timing starts when the command is run, so it is important to account for system delays and compensate for them in the software.

In addition, when measuring the liquid level with ultrasonic waves, the distance to the liquid level is the distance from the front end surface of the probe to the liquid level. In fact, the acoustic center of piezoceramics is not located on its surface. Therefore, the distance from the probe surface to the acoustic midpoint will also introduce systematic errors, which can be classified as time delay differences and corrected together.

For the same type or the same batch of ultrasonic level transmitters, due to the use of the same components, materials and processes, the system delay is almost the same and is relatively fixed. Thus, the time delay of the system can be calibrated and corrected by checking the fixed distance.

Experimental studies are carried out to check the accuracy of the measurement of the system. During the experiment, the ambient temperature is 25°C, the frequency of the ultrasonic transducer is 40 kHz, and the water level detection data is compared with the standard level change value in the range of 2000mm.

The measuring system takes 12 measurements while the program is running, and 12 measurements are averaged to reduce random system error. Experimental measurement data are presented in Table 1 and Fig. 3.

Table 1. Experimental measurement data are presented.

Distance installed by nominal partition	The order of measurements												error, %
	1	2	3	4	5	6	7	8	9	10	11	12	
200	199,2	198,7	200,3	199,6	198,7	199,5	198,7	199,5	198,7	199,4	198,7	198,2	0,45
400	399,2	401,7	403,3	399,6	401,7	399,4	401,7	399,1	401,7	399,2	401,7	401,1	0,195
600	601,6	599,9	601,3	601,1	599,9	601	599,1	601,3	599,9	601,4	599,8	599,4	0,075
800	797,3	798,4	798,3	797,3	798,4	797,3	798,4	797,3	798,4	797,3	798,9	798,4	0,25
1000	997,8	998,3	997,4	997,1	998,6	997,8	998	997,8	998,8	997,8	998,2	998,5	0,19
1500	1503	1505	1504	1506	1505	1503	1504	1504	1505	1504	1505	1504	0,28
2000	1993	1997	1996	1993	1997	1993	1997	1993	1997	1993	1997	1996	0,24

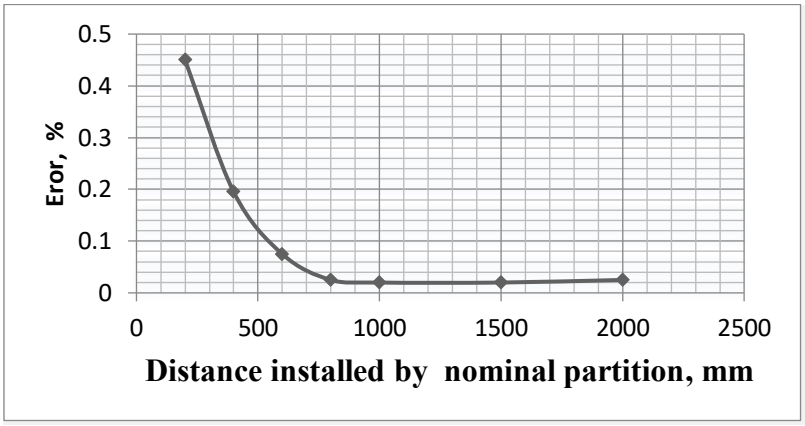

Fig. 3. Error value at different distances.

From the experimental data, it was found that the result of ultrasonic measurement of the liquid level lies in the range of 0.01 - 2%.

3 Conclusion

Several basic measurement errors of the ultrasonic level gauge are analyzed and a correction method is proposed. According to the above calibration method, the measurement accuracy is greatly improved, and it has temperature compensation, high accuracy and strong adaptability; a special echo processing method is applied to effectively avoid false echoes; which can be applied in various industrial environments. Therefore, in the measurement process, it is necessary to use microprocessors and computing systems for sensors, which reduces the quality requirements of the components from which the measuring circuit is built. The introduction of periodic and automated zeroing and calibration processes into the algorithm of equipment operation allows you to programmatically compensate for changes in the parameters of measuring elements, as well as to exclude the influence of these changes on the accuracy of measurements. Automatic zeroing depends on periodic testing of the circuit's response to a zero input signal. Autocalibration is carried out by a sequence of measurements for different values of the reference signal at the output of the equipment and for different volumes of equipment. The responses are stored in the memory of the equipment and are used to adjust the results before they are transmitted to the operator.

References

1. N. R. Yusupbekov, A. A. Yusupov, International Journal of Advanced Science and Technology 29(9s), 5370-5380 (2020)
2. L. Bergman, Ultrasound and its application in science and technology (Foreign Literature, Moscow, 1957)
3. L. Way, L. Szyan, L. Sayan, Electronic Measuring Technologies **31 (1)**, 91–93 (2008)
4. V. Barshan, Measurement Science and Technology **11 (1)**, 45-50 (2000)
5. B. V. Jukov, Sensors and Systems **2**, 35-40 (2007)
6. F. Bayle, Impact at the Reliability Level. Reliability of Maintained Systems Subjected to Wear Failure Mechanisms (2019) DOI: 10.1002/9781119610717.ch4.