ISSN 1392-2114 ULTRAGARSAS, Nr.4(61). 2006.

Non-invasive ultrasonic level measurement technology

A. Petrauskas

Kaunas University of Technology, Prof. K.Baršauskas Ultrasound Institute

Abstract

Non-invasive ultrasonic echolocation method for measuring level of various liquids is proposed. Measured distance from the acoustic antenna to the material is calculated a function of the temperature influence. The experimental dependence of acoustic signal speed in chemically purified water with temperature range 0…250°C is used in realisation of level meter. Non-invasive echolocation level meter to measure the water level in pressurized tanks of power stations, boiler houses and other areas is described. The application of this method in the optimization of technological processes has been proved.

Keywords: acoustic measurement method, acoustic echolocation method, echolocation method for measuring level of various liquids, measurement of level liquid.

Preface

An ultrasonic measurement method [1, 2] together with a microwave echolocation method gained a widespread popularity for measuring level of various liquids. The ultrasonic method has an advantage over the microwave method, because the measurement itself can be done not only from above the liquid but also from below – through the material itself. When measuring from the top, the physical and mechanical properties of the liquid have no effect to the result and the measurement device can be mounted on the top of a tank with liquid. In this case, the gaseous environment, through which the measurement takes place, affects the measurement results. Mostly the results are affected by the environment temperature, because the temperature has the biggest effect on the propagation of acoustical waves. To eliminate or at least minimize this effect the temperature needs to be measured along the entire signal propagation path.

Method

The measured distance L from the acoustic antenna to the material is calculated using this expression:

$$L = 0.50\,(T_M - T_{kor})\,(1402 + k_t\,t,°\mathrm{C}), \qquad (1)$$

where T_M – the signal‘s propagation time from the antenna to the surface; T_{kor} – correctional time interval; k_t – correction coefficient; t – temperature of the liquid. The unit must have the option to enter the dependence $k_t = f(t,°\mathrm{C})$ in a table. In practice, 8 points are sufficient.

When measuring from below the liquid (when the signal propagates through the medium itself) the measurement results depend on the physical and mechanical properties of the liquid. In this case, it is best to perform measurement of a precisely known distance. This enables us to eliminate the effects of temperature and chemical composition of the liquid to the measurement results. In practice, the most common need is to measure the level of a particular liquid, so the evaluating the propagation speed of acoustic waves in a given material is a straightforward process. In practice, the liquid has different temperatures in different regions of the tank, so the signal has to propagate through regions of uneven temperature. Keeping this in mind, we need to place up to 20 temperature sensors in the path of the signal, and they must be placed in an even distance from one another.

The speed of acoustic waves in liquid can be a complex function (for example, water in temperature range 0...250°C). In this case, we need to evaluate the signal speed Vn in every temperature measurement point and calculate the average signal speed as a sum. Now we calculate the level of the liquid using this expression:

$$L = (T_M - T_{kor})\cdot(V_1 + V_2 + ... + V_n), \qquad (2)$$

where V_1, V_2,… – the signal‘s propagation velocities from the antenna to the surface.

Our non-invasive echolocation level meter (Fig. 1) is designed to measure the water level in pressurized tanks of power stations and boiler houses. This meter can measure a water level in high-pressure (up to 200 atmospheres) tanks when the water temperature is in the range 0...300 °C. To evaluate the speed of acoustic waves there are four temperature sensors mounted on the tank.

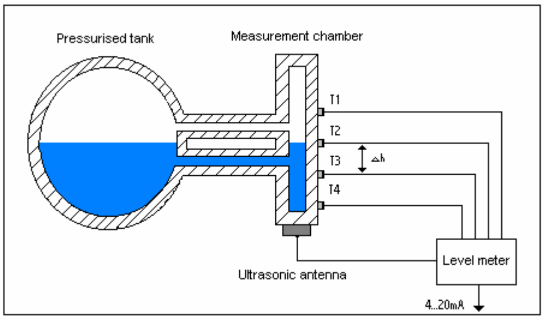

Fig. 1. **Schematics of echolocational acoustical non-invasive water level meter: T1-T4 – temperature sensors**

Experimental part

When measuring water level in a wide range of temperatures, for example, in the pressurized tanks of power stations, we need to know the propagation speed of acoustic waves in chemically purified water with temperatures in 0...250 °C. Such temperature can be in the pressurized tank (Fig. 1). To keep water in a liquid state at such high temperatures the pressure must be at least 90 atmospheres.

In literature [3-4], we can find information about the speed of sound in a wide temperature range (Fig. 2, theoretical curve).

To improve the accuracy of our echolocational acoustical level meter we had to verify whether the speed of sound matches the curve below.

To do this we carried out measurements of acoustic signal speed in chemically purified water with temperatures in 20...240 °C.

We chose a pressurized tank with 16 mm thick walls and 1.5 m in length. It had a pressure measurement equipment with valves and was filled with chemically purified water. Piezoceramic transducers were mounted on the protective layer on tank‘s end. The protective layer was protecting the transducers from overheating and damage.

The tank was thermally insulated and fully filled with water. Then placed horizontally over four gas burners. Holes were made in the insulator to let the fire get directly in contact with tank.

The tank‘s wall temperature was measured at 6 points (3 on the top and 3 on the bottom). We note that 4 points would have also been enough because the temperature difference was less than 2°C. All temperature sensors were mounted on the tank‘s wall beneath the thermal isolator.

By using an echolocational level meter [5] we measured the time interval, in which the acoustical 800 kHz frequency signal traveled the distance of 3100 mm, e.g., for measurements the signal reflected from the tank‘s end was used.

Measurements were done when both heating and later cooling the tank. The duration of one cycle was approximately 12 hours. The excess pressure was removed through the valve and the pressure was around 90 atmospheres.

The results are presented in Fig. 2.

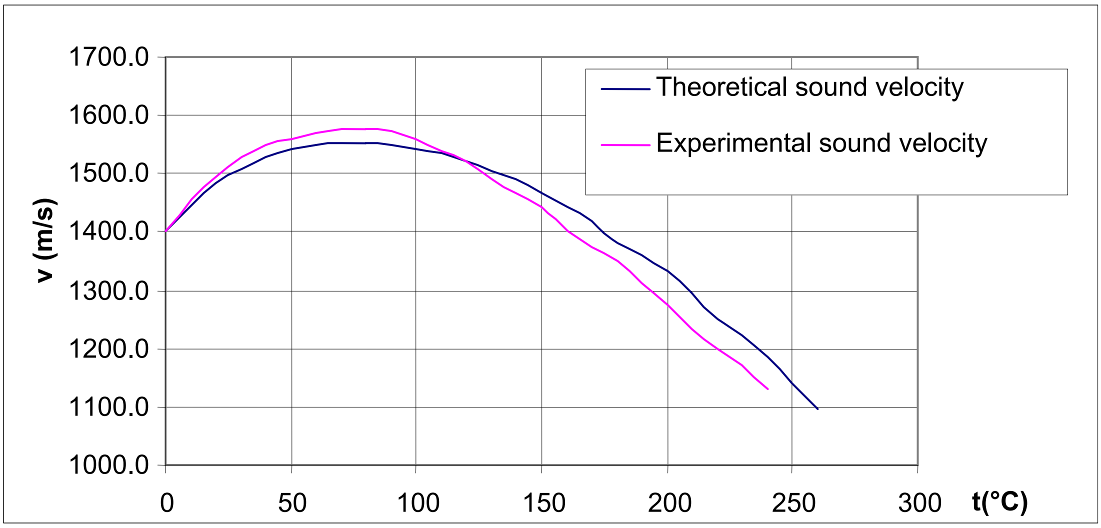

Fig. 2. **The dependence of acoustic wave speed in water on temperature**

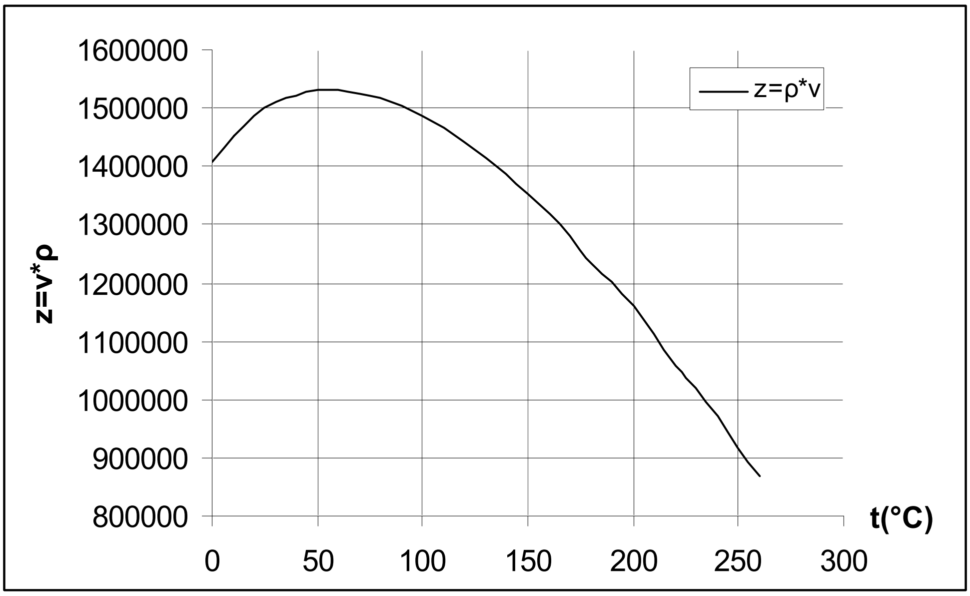

Fig. 3. **The dependence of water acoustical impedance *z* on temperature**

Table 1. **The speed of acoustic waves V and water density ρ versus temperature. The pressure is 100 and 160 atmospheres.**

t (°C)	V_{100} (m/s)	V_{160} (m/s)	ρ_{100} (kg/m^3)	ρ_{160} (kg/m^3)	$z = \rho * v$
0	1402,5	1402,25	1004,6	1007,6	1408952
10	1446,7	1457,60	1004,3	1007,0	1452921
20	1482,9	1493,78	1002,7	1005,3	1486904
30	1509,4	1528,59	1000,0	1002,6	1509400
40	1527,9	1550,45	996,5	999,0	1522552
50	1542,1	1560,10	992,3	994,8	1530226
60	1550,2	1570,20	987,5	989,9	1530823
70	1553,8	1575,80	982,0	984,5	1525832
80	1553,9	1575,78	976,1	978,7	1516762
90	1550,1	1571,45	969,6	972,3	1502977
100	1542,8	1560,65	962,7	965,4	1485254
110	1533,7	1538,54	955,5	958,2	1465450
120	1521,1	1520,20	947,7	950,6	1441546
130	1505,9	1490,56	939,6	942,6	1414944
140	1489,9	1467,45	931,1	934,2	1387246
150	1465,8	1441,25	922,2	925,4	1351761
160	1442,9	1402,50	912,8	916,2	1317079
170	1418,9	1372,65	903,0	906,6	1281267
180	1381,8	1350,25	892,8	896,5	1233671
190	1360,9	1310,89	882,1	886,1	1200450
200	1331,6	1275,85	870,9	875,2	1159690
210	1294,0	1233,74	859,2	863,8	1111805
220	1250,4	1200,10	847,0	851,8	1059089
230	1222,0	1170,56	834,0	839,3	1019148
240	1186,1	1130,20	820,3	826,0	972958
250	1139,5		805,9	812,1	918323
260	1096,9		790,4	797,4	866990
270			773,9	781,7	
280			756,1	764,9	
290			736,6	746,8	
300			714,9	727,1	
310				705,2	
320				680,6	
330				651,9	
340				616,6	

The values of acoustic wave speed: theoretical and experimental with pressure being 100 and 160 atmospheres (results published by Preobrazenskij B.P.), and the calculated values of the acoustic impedance versus the temperature are shown in Table 1. The variation of the acoustic impedance is shown in Fig. 3.

The temperature dependencies of water density are presented in Fig. 4. We can see that the pressure has a little effect on the density of water. It mostly depends on temperature.

Acoustic impedance of water at the temperature 260°C declines almost 2 times and the propagation of acoustic signals at such high temperatures becomes problematic.

The experimental dependence of acoustic signal speed on temperature is exploited in our level meter.

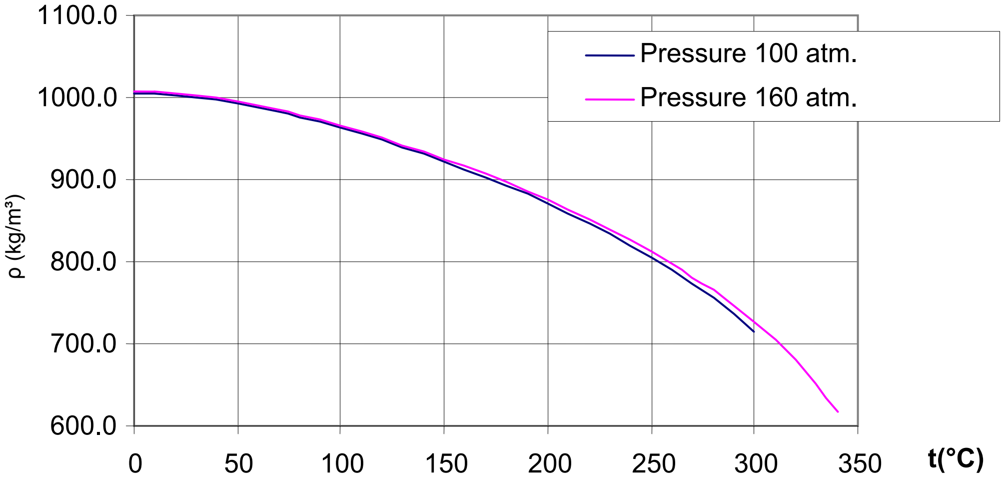

Fig. 4. **The dependence of water density on temperature**

The experimentally obtained speed of acoustic wave in a chemically purified water enabled us to increase the measurement accuracy by 15 %. We note that in practice the temperature difference between the pressurized tank and measurement chamber is around 80°C, so the differences of water density have to be taken into account.

When designing the echolocational acoustical level meter we had to evaluate the influence of a high pressure and temperature to our equipment. The steam generators in power stations are 20 meters long and 3 meters wide. Their wall thickness is 100 mm and thermal insulation is very good. The only way (due to temperature, thick walls and boiling water) to measure water level in such tanks is to have a connecting measurement chamber as shown schematically in Fig. 1.

The measurements of a water level using an ultrasonic method can only be done without an invasion into the pressurized tank. It is best to mount the acoustic antennas (piezoceramic transducers) on the bottom of the tank and then measure the distance to the surface of water through the tank‘s wall.

When doing echolocational measurements we have also faced the problem of heat interchanges in the measurement tank. This is because a 300-330°C steam gets into the tank and condensation process begins. During this process, great heat interchanges occur. The interchanges cause intensive waters currents in the tank. In the tank‘s upper part the temperature reaches 330°C, but on the bottom – around 200°C. That is why temperature measurements must be done along the signal propagation path. Then using Eq. 2 the propagation time of the acoustic signal can be evaluated. This is implemented in the developed level meter.

Fig. 5 and Fig. 6 show water level variations in a pressurized tank measured simultaneously with a standard differential pressure meter and the developed level meter.

Using this data, we can see that the ultrasonic level meter is less sensitive to pressure variations. This is because the pressure has a little effect on the acoustic wave speed. Using the measurement results we see that it is also possible to integrate the acoustical level meter in the automatic control system because it‘s measurements is more stable. At this moment in „Lietuvos elektrinė“ power plant the tests of our equipment are being done. The aim is to integrate our equipment into the automatic control system.

Conclusions

When measuring water level in sealed tanks in a wide temperature interval the propagation of ultrasonic signals needs to be improved.

Also when measuring in a wide temperature ranges, temperature measurements must be done along the signal‘s propagation path.

The practical water level measurement results, obtained at the „Lietuvos elektrinė“ power station, show the possible uses of such level meters to monitor a level in various tanks.

References

1. **Olmos P.** Extending the accuracy of ultrasonic level meters. Meas. Sci. Technol. 2002. Vol.13. P.598-602; doi:10.1088/0957-0233/13/4/324
2. **Minialga V., Petrauskas A.** Acoustic echolocation method for evaluation of porosity and corrosion of materials. Controles non destructifs CND & corrosion Congres COFREND 2001, Reims. 24 Au 26 avril 2001. P. M1-6.
3. **Chavez M., Sosa V.** Speed of sound in saturated pure water. JASA. 1985. Vol.77 (2). P. 420-423.
4. **Chen Ch., Millero F.** Reevaluation of Wilsons sound-speed measurements for pure water. JASA. 1976. Vol.60 (6). P. 1270-1273.

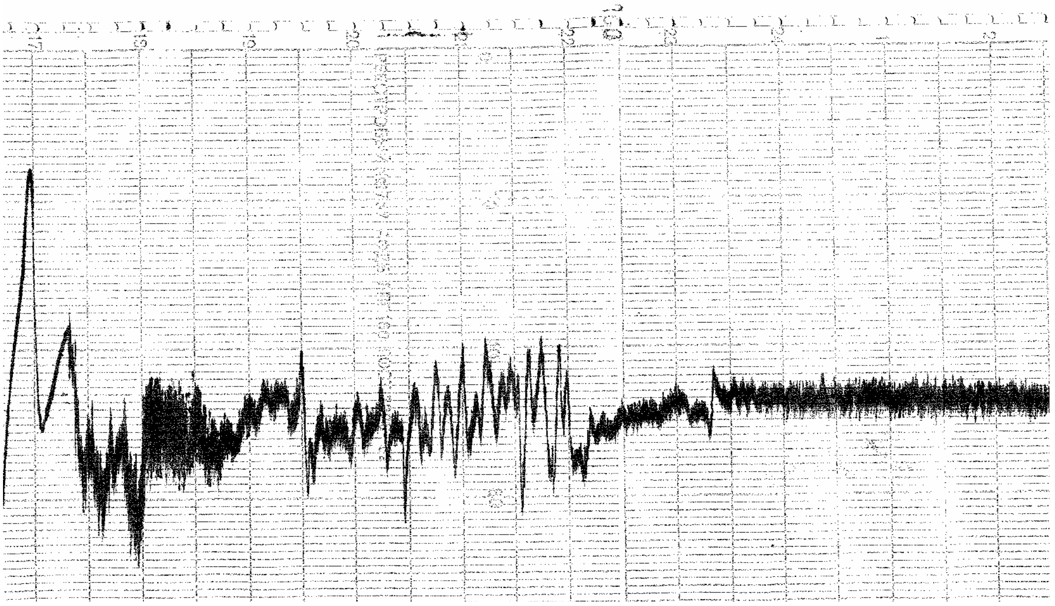

Fig. 5. **Water level measured with a standard differential pressure meter: one vertical graduation equals 1 centimeter of water level and one horizontal graduation equals a time interval of 5 minutes**

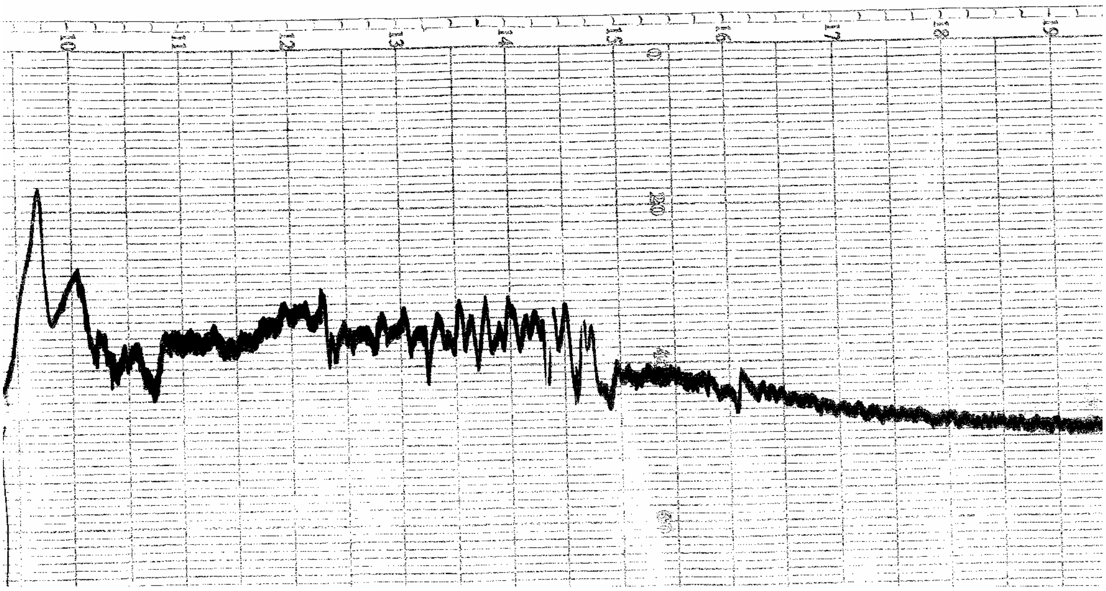

Fig. 6. **Water level measured with our acoustic level meter: one vertical graduation equals 1 centimeter of water level and one horizontal graduation equals a time interval of 5 minutes**

5. **Swamy K., Narayana K.**. Study of temperature variation of ultrasonic velocity in heavy water. ACUSTICA. 1984. Vol. 54. P.230-234.

6. **Petrauskas A., Razutis P.** Investigation of echolocational ultrasonic methods by increasing accuracy in level measurements. Ultragarsas (Ultasound). Kaunas: Technologija. 2001. Nr.4(41). P.18-21.

A. Petrauskas

Ultragarsinė neinvazinė lygio matavimo technologija

Reziumė

Aprašyta neinvazinė ultragarsinė vandens lygio matavimo didelio slėgio ir temperatūros induose metodika. Pateikti ultragarsinių signalų sklidimo matavimo inde tyrimų rezultatai. Pasiūlyta matavimo indo konstrukcija, įgalinanti pasiekti praktikoje pakankamą vandens lygio matavimo tikslumą. Gautoji ultragarsinių signalų laikinė temperatūrinė priklausomybė palyginta su literatūroje esančiais duomenimis. Aptarti vandens lygio matavimo slėginiuose induose ypatumai ir pateikta siūlymų, kaip tokius matavimus įgyvendinti praktikoje. Pateikti eksperimentiniai matavimų rezultatai.

Pateikta spaudai 2006 06 15