A NOVEL DETECTION OF VESSEL LIQUID LEVEL BASED ON ECHO IDENTIFICATION[1]

Zhaohui Zhang[a], **Jianmei Yuan**[b], **Weiyi Huang**[c]

[a]*Faculty of Information Engineering, University of Science and Technology Beijing, China*
[b]*Faculty of Applied Science, University of Science and Technology Beijing, China*
[c]*Department of Instrumentation, Southeast University, Nanjing, China.*

Abstract: A novel non-invasive level detection is developed in the paper for applications to processes where high pressure, high temperature, high viscosity, strong corrosion liquid may be involved. The theoretical analysis and experiment suggest that the proposed echo method can measure level well. The key to the success of this detection is the proper extraction of the echo information from noisy waves by using a proper Wavelet Transform.

Keywords: Detecting elements, Vessel level, Non-invasion meter, Echo extraction, Wavelet Transform

1. INTRODUCTION

In situations, where high pressure, high temperature, high viscosity, or corrosive liquid or vapors are involved, the liquid level measurement can be difficult, as it is not allowed for a sensor invasion. Ultrasonic and radar level meters, which can avoid any direct contact with liquid, have to be installed inside of the vessel. They aren't adoptable for applications where high pressure or for corrosive vapors involved. Radioactive meter, which is non-invasion in nature, can not be conveniently used, as it needs special protection, storage, and encapsulation. A novel non-invasion measurement method is proposed by this paper based on proper processing of echoes for level detection.

2. PRINCIPLE OF LEVEL DETECTION

Three parts of different waves can be resulted from the striking of a vibrator against the metallic shell of the vessel. The significant part, a surface wave, propagates along the external surface of the vessel. The second part, echo, penetrates the shell and then is reflected on the internal surface, i.e, the interface of metal/liquid or metal/atmosphere. The third part, transmission wave, penetrates the shell and then is absorbed by the liquid or atmosphere. Both surface wave and echo can be sensed at a properly placed receiver, as illustrated by Fig.1.

As the thickness of the shell is much smaller than the radius of the vessel, the area around the receiver can be regarded as a plate. This helps to assess the inherent frequency to the selection of the receiver (Zhang and Huang,1999).

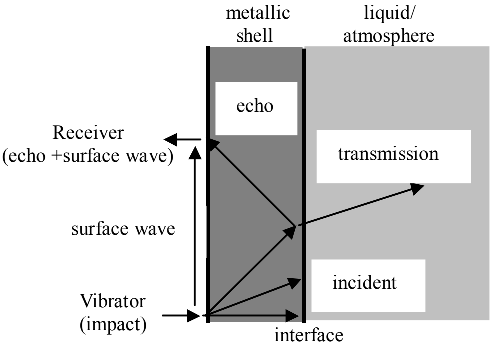

Fig.1. Vibrato rand receiver

Now we focus on the echo. For simplification, suppose the echo is of one dimension. The impedance of wave conductor is defined as (Brekhovskih, 1980):

$$Z = c\rho \qquad (1)$$

Where ρ is the density and c is the sound velocity in the conductor. At the interface of conductor 1 and conductor 2, reflection coefficient is

$$C_r = \frac{Z_2/Z_1 - 1}{Z_2/Z_1 + 1} \qquad (2)$$

And the transmission coefficient is

$$C_t = \frac{2 * Z_2/Z_1}{Z_2/Z_1 + 1} \qquad (3)$$

As an example, consider a steel vessel filled with water. The impedances of steel, water and atmosphere are

$$Z_s = c_L\rho = 5790\text{m/s} * 7910\text{Kg/m}^3 = 4.58*10^7\text{Kg/m}^2\text{s}$$
$$Z_w = 1483\text{m/s} * 1000\text{Kg/m}^3 = 1.48*10^6\ \text{Kg/m}^2\text{s}$$
$$Z_a = 331.45\text{m/s} * 1.2250\text{Kg/m}^3 = 4.06*10^2\ \text{Kg/m}^2\text{s}$$

Thereby reflection and transmission coefficients at the interface of steel and water are

$$C_r^{s/w} = \frac{Zw/Zs - 1}{Zw/Zs + 1} = -0.9374$$

$$C_t^{s/w} = \frac{2 * Zw/Zs}{Zw/Zs + 1} = 0.0626$$

At the interface of steel and atmosphere (empty segment), the coefficients are

---

[1] This work was supported by UPC Grant ZX9914 and Grant BJ97026.

$$C_r^{s/a} = \frac{Za/Zs-1}{Za/Zs+1} = -0.99998$$

$$C_t^{s/a} = \frac{2*Za/Zs}{Za/Zs+1} = 0.00002$$

It can be seen that $C_t^{s/w} >> C_t^{s/a}$ and $C_r^{s/w} < C_r^{s/a}$ in their absolute values. Generally, the liquid impedance is close to that of the metallic shell, whereas the atmosphere impedance is much smaller than that of the metallic shell, i.e, $C_r^{s/l} < C_r^{s/a}$. Hence, echo exists only above the liquid level, little exists beneath the level due to attenuation. This conclusion is independent of the vessel construction, size, shell materials, and liquid types.

By moving the vibrator and receiver up or down along the vessel surface, the level can be found via echo identification.

3. SIGNAL PROCESS

The receiver signal includes two parts, surface wave and echo. It's difficult to recognize echo from the original received signals. A signal process technique is developed, next, to distinguish echo from the significant surface waves. Both signals, which are time-varying, attenuate rapidly during propagation (Breining, 1999). Therefore, Wavelet Transform is applied for their processing.

Wavelet Transform is a linear transformation that operates in time-frequency joint domains (Cohen, 1995). Its Mallat fast algorithms are

$$C_{j+1,k} = \sum_{n\in Z} \overline{h}_{n-2k} C_{j,n} \tag{4}$$

$$D_{j+1,k} = \sum_{n\in Z} \overline{g}_{n-2k} C_{j,n} \tag{5}$$

where h_n and g_n are constant coefficients for a specific wavelet function. For discrete signal $C_{0,k}$ (k integer), series of coefficients $C_{j,k}$ represent the jth-order approximations, i.e, the components below frequency $(\omega_c - \Delta)2^{-j}$, where ω_c and Δ are center frequency and window width determined by wavelet function. And $D_{j,k}$ represent the jth-order details.

Take the discrete receiver signal f(k) (k=1,2,…,N) as initial conditions

$$C_{0,k} = f(k) \tag{6}$$

A simplest wavelet function, Harr, is adopted with coefficients $h_0=0.707107$, $h_1=0.707107$, $g_0=-0.707107$, $g_1=0.707107$. Harr is compactly supported (h_k, $g_k=0$ if $k>1$) so that a good computation efficiency would be achieved.

The approximations $C_{3,k}$ and details $D_{j,k}$ (j=1,2,3) can be worked out via algorithms (4) and (5) iteratively. Refer to Fig 2. The 3rd-order approximations $C_{3,k}$ are components below the frequency $(\omega_c - \Delta)2^{-3}$. All wave crests appear periodically in $C_{3,k}$, whereas a special crest appears at a phase-shift. This suggests that the special waveform segment is the echo that we are interested to identify.

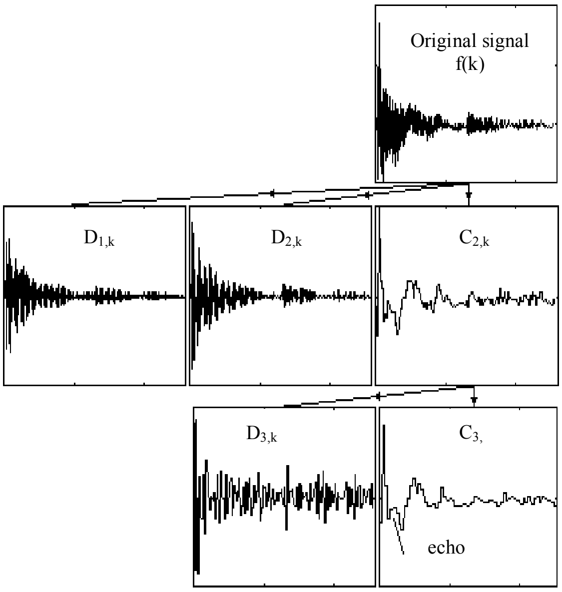

Fig.2. Receiver signal and its wavelet transforms

4. EXPERIMENT

Consider a steel vessel with 1m diameter and 1m height and being filled with 80% water. Exert a pulse strike to the shell of vessel so that a wide frequency range is excited. Touch the receiver to the shell with a little press. Move the detection point down step by step.

The 3rd-order approximations $C_{3,k}$ of the receiver signals are presented in Fig.3. Echo can be found right above the level, and disappears beneath the level.

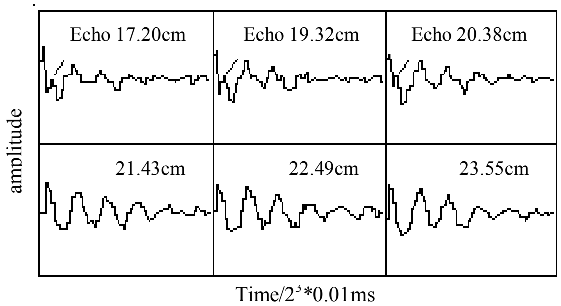

Fig.3. The 3rd–order approximations at 6 detect points

Where, the number above the line in all the four graphs represents the distance between the detect point and vessel top, the actual distance from the vessel top to the liquid surface is 20.00cm.

The level detection resolution error is less than one step, independent of the measurement span. This simple device can have high precision, particularly for large vessels.

5. CONCLUSIONS

Based on the identification of echo, a non-invasion liquid level detection system has been developed. The application of wavelet transform is the key for distinguishing the weak echo from the noisy surface waves. The authors believe such a method can be easily extended for the detection of the powder surface in vessel.

REFERENCES

Christina Breining (1999).
Acoustic Echo Control. *IEEE Signal Processing Magazine*, Vol.16,No.4, pp42-69
Leon Cohen (1995).
Time-Frequency Analysis:Theory and Applications, Prentice Hall, 1995
L.V.Brekhovskih (1980).
Waves in Layered Media, Academic Press, New York.
Zhaohui Zhang, and Weiyi Huang (1999).
A Liquid Measurement Method Based on Vibration Analysis. *Chinese Journal of Scientific Instrument,* Vol.20, No.3, pp250-253. (In Chinese)