Electrical Measurement Method of Multiple Boundaries in Liquid Medium

Yumi Takizawa, Atsushi Fukasawa, and Masaji Abe

***Abstract*—**This paper presents novel measurement method of multiple boundaries in liquid medium using both components of transmission and reflection signals. Electrical method is first shown to calculate the position of a boundary in a section of liquid transmission line. Then a method to calculated positions of two boundaries between three liquid zones. Configuration of measurement system is shown lastly for multiple boundaries formed in liquid medium with cascaded connection of the Chirp and the proposed methods.

***Keywords*—**Liquid boundary, transmission and reflection signals, Chirp method, cascaded signal processing.

I. Introduction

MEASURMENT methods of position of liquid surface is required widely in industrial domain for storage, transportation, and production and control of domain of liquid materials.

The chirp method using microwave reflection at liquid surface has been utilized commonly for materials with relatively high reflection at the surface. This method is not applied for materials with relatively low reflection of microwave at the surface.

Recently novel methods are requested for materials with very low reflection of microwaves at the surface. Furthermore fine resolution is requested for measurement of the boundary position between the air and the liquid.

Wave (signal) reflection method is not applied because of small reflection at the surface. Wave transmission method is not used practically, because so many components of signal wave are required to get the solution of boundary position.

This paper first gives novel measurement method using transmission and reflection components signals simultaneously.

This paper then gives a novel measurement scheme composed of the proposed method and conventional chirp method with cascaded connection for fine resolution of positioning against long transmission line.

This system will be used for system of liquid surface positioning in wide and practical areas.

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II. Estimation of Position of Boundaries

A. Transmission of Electric Signal in Inhomogeneous Medium

In inhomogeneous mediums, relative dielectric constant is assumed as $\varepsilon_r(y)$, which depends on position at neighbor of *y*. Velocity $c(y)$ at point *y* is given as follows.

$$c(y) = \frac{c_0}{\sqrt{\varepsilon_r(y)}} \tag{1}$$

where, c_0 is the velocity of light in vacum. Electrical signal trasmission time *T* is calculated as follows.

$$T(y) = \int_0^y \frac{\eta}{c(\eta)} d\eta \tag{2}$$

B. Signal Transmission of Electrical Signal in Discontinuous Medium

Figure 1 shows configuration of an inhomogenoeous transmission line. A medium boundary (or liquid surface) is included at a certain position of the line. A measurement system must provide fine resolution for decision of boundary position against long tranmission line length.

A measurement method is given by sectionning of whole span into a boundary section and the other sections without boundary as shown in Fig. 1. The transmission line is devided into *N* sections. A section *k* is defined by positions $p_{k-1}$and p_k . A boundary is included at a section *n* , *n* is unknown.

Positions $p_{k-1}$and p_k are defined as reflection points. p_0 is transmission point of electrical signal, and p_N is end point of transmission line.

It is considered that some obstercles are inserted at points p_1 ~ p_{N-1} along *y* axis to yield small reflection of electrical signals.

The length of section k is x_k (k = 1, …, n, .. , N). The position of boundary is p_{Bn} in n-th section. δ_n is the distance from p_{n-1} to p_{Bn}.

The passing time t_k in the section k without boundary is given as;

$$t_k = T_k - T_{k-1} = \frac{x_k}{c_k} \quad (3)$$

The velocity c_k in section k is given as;

$$c_k = \frac{x_k}{t_k} \quad (4).$$

where, t_k is passing time in section k.

Now, boundari section is considered.

Passing time t_n of boundary section n is given by velocities c_{n-1} *and* c_{n+1} at the preceeding and the post sections adjacent to the section n.

$$t_n = T_n - T_{n-1} = \frac{\delta_n}{c_{n-1}} + \frac{x_n - \delta_n}{c_{n+1}} \quad (5)$$

$$= \frac{\delta_n\, c_{n+1} + (x_n - \delta_n)\, c_{n-1}}{c_{n-1}\, c_{n+1}} \quad (6)$$

$$= \frac{\delta_n\, (c_{n+1} - c_{n-1}) + x_n\, c_{n-1}}{c_{n-1}\, c_{n+1}} \quad (7)$$

The position of boundary at y_{Bn} is given as follows;

$$y_B = y_{n-1} + \delta_n \quad (8)$$

$$\delta_n = \frac{(T_n - T_{n-1})\, c_{n-1}\, c_{n+1} - x_n\, c_{n-1}}{\{ c_{n+1} - c_{n-1} \}} \quad (9)$$

$$= \frac{c_{n-1}\, c_{n+1}}{c_{n+1} - c_{n-1}} \left\{ (T_n - T_{n-1}) - \frac{x_n}{c_{n+1}} \right\} \quad (10).$$

C. Measurement of Boundary Position

(1) Detection of boundary section

Difference of velocity ε_k is considered between adjacent sections.

$$\varepsilon_k = |\, c_{k-1} - c_k \,| \quad (11)$$

The value of ε_k is larger than values at the other sections in transmission line.

By iterative calculation of k (1~N), the section n with the maximum value ε_n is given as follows.

$$n = \left\{ k \,\middle|\, \max_k \left(|\, c_{k-1} - c_k \,| \right) \right\} \quad (12).$$

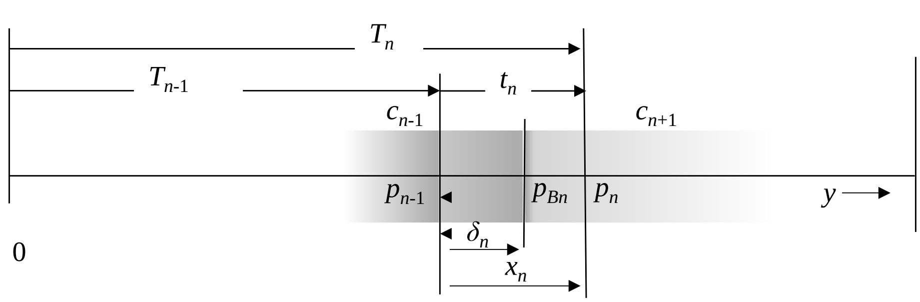

Fig.1 Structure of a section n with a boundary at point p_{Bn}.

(2) Measurement of velocities c_{n-1} and c_{n+1}

The adjacent velocities c_{n-1}, c_{n+1} (n = 1 ~ N) are considered. Except boundary section n, the velocities of the other sections are equal to c_1 and c_N respectively

$$c_1 = \frac{x_1}{T_1 - T_0} \tag{13}$$

$$c_N = \frac{x_N}{T_N - T_{N-1}} \tag{14}$$

where, T_0 is 0, and c_0 is the velocity of signal in the air.

The time of T_1 ~ T_N are given in experiments.

III. Measurement System for a Single Boundary

A. The Chirp method

The transmission times T_k are calculated in chapter II.

Here, these times are obtained by the chirp method.

Chirp signal is made of single carrier modulated by triangle wave. The chirp signal is transmitted and reaches to reflection points p_1, .., pn, .., pN and liquid boundaries in a neuron. The reflection signals from these points and boundaries are received at p_0.

Then the transmission signal s_t and receiving signal s_r are mixed with different frequency. The beat frequency Δf becomes as follows;

$$\Delta f = f_t - f_r = 2\alpha T_C \tag{15}$$

$$\alpha = \{ f_t(\max) - f_t(\min) \} / T_0 \tag{16}$$

where, f_t and f_r are frequencies of transmission and receiving when the signals are mexed. T_C is transmission time from p_0 to reflecting point. α is chirp modulation parameter difined by maximum and minimum frequencies of f_t (max), f_t (min), and T_0 is the time length of triangle wave for chirp modulation.

Then the transmission time T_C is obtained by the following.

$$T_c = \Delta f / 2\alpha \tag{17}$$

Transmission time between reflection points and each boundary is calculated by frequency deviation between transmission and receving signals.

B. System Configuration

A system configuration is shown in Fig. 2. The left part is the chirp method, and the right part is the proposed method, which is connected by cascading to the chirp method.

The part of the chirp method outputs times of reflection components T_1 ~ T_N , and T_{Bn}. These times are transmission time from point $p0$ to each reflection point.

The part of the proposed method outputs position of boundary p_{Bn} with fine resolution for input times T_1 ~ T_N , and T_{Bn} .

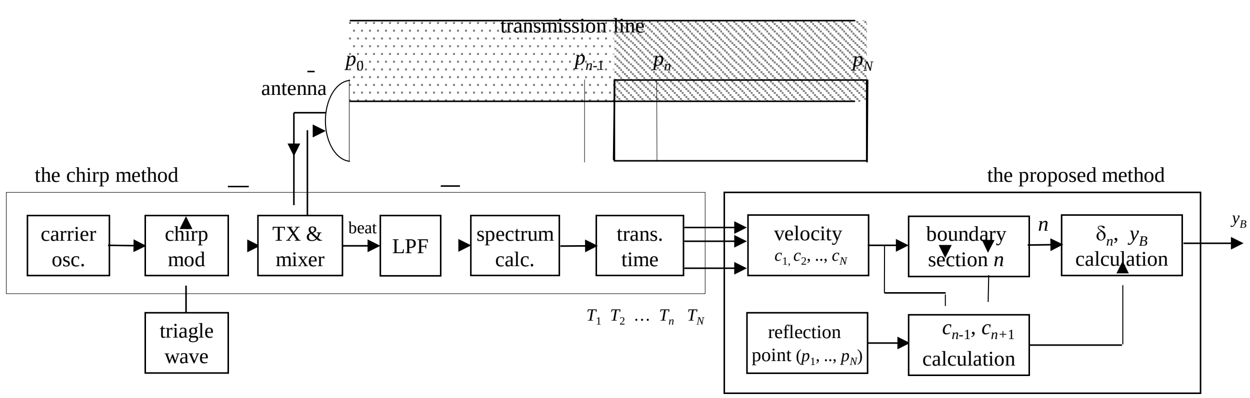

Fig. 2 System configuration of electrical measurement scheme.

IV. Measurement of Positions of Plural Boundaries

Six reflection objects are considered to be inserted in the medium. By a pair of reflection objects ($g0$, $g1$), ($g2$, $g3$), and ($g4$, $g5$) in each zone, uniform velocities are measured at input and output zones without boundary.

$$c_1 = \frac{x_1}{T_1} \tag{18}$$

$$c_3 = \frac{x_3}{T_3 - T_2} \tag{19}$$

$$c_5 = \frac{x_5}{T_5 - T_4} \tag{20}$$

Then the positions of two boundaries enclosing the central part are calculated as;

$$\delta_2 = \frac{c_1 \; c_3}{c_3 - c_1} \left\{ (T_2 - T_1) - \frac{x_2}{c_3} \right\} \tag{21}$$

$$\delta_4 = \frac{c_3 \; c_5}{c_5 - c_3} \left\{ (T_4 - T_3) - \frac{x_4}{c_5} \right\} \tag{22}$$

The positions p_{B2} and p_{B3} in section 2 and 3 are obtained by substituting Eq (14) and (15) into Eq.(8).

V. Conclusion

This paper presented novel measurement method utilizing transmission and reflection components of signals simultaneously.

This paper then presented a novel measurement scheme composed of the proposed method and conventional chirp method with cascaded connection.

The proposed method is applied to practical liquid transmission equipment under construction.

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References

[1] Takizawa Y., Fukasawa A., “Electrical Measurement Scheme of Liquid Boundaries in Active Neuron”, to be published on *Proc. of Int. Conf. on Health Science and Biomedical Systems (HSBS’14)*, Nov. 22, 2014.

[2] Takizawa Y., Fukasawa A., “Signal Processing by a Neural System and its application to location of multiple events,” International Journal of Applied Mathematics and Informatics, Issue 3, vol. 6, pp. 126-133, 2012.

[3] Takizawa Y., Fukasawa A, “Formulation of a Neural System and Modeling of Topographical Mapping in Brain,” Proc. of International conference on Circuit, Systems, Control, Signals (CSCS’12) , pp.59 - 64, Barcelona, Spain, Oct. 17, 2012.

[4] Takizawa Y., Fukasawa A., “Formulation of a Neural System and Application to Topographical Mapping,” Proceedings of the 3rd International Conference on Neurology (NEUROLOGY '12), pp. 248-253, Kos Island, Greece, July 14-17, 2012.

[5] Takizawa Y., Fukasawa A., “Organization of a Neural System and its Operation for Sensing of Multiple Events in 3D space,” Proc. of International Conference on Biomedicine and Health engineering (BIHE’14), pp. 112-118, Tenerife, Spain, Jan. 10, 2014. Tenerife, Spain, Jan. 2013.

[6] Castsigeras E. “Self-synchronization of networks with a strong kernel of integrate and fire excitatory neurons,” *WSEAS Transactions on Mathematics*, Issue 7, Vol. 12, pp. 786 – 797, July 2013.

[7] Takizawa Y., Fukasawa A., Formulation of Topographical Mapping in Brain with a Synchronous Neural System, *Proceedings of the 15th International Conference on Mathematical Methods, Computational Techniques and Intelligent Systems (MAMECTIS’13)*, pp. 60–65, Lemesos, Cyprus, Mar. 21-23, 2013.

[8] Fukasawa A. Takizawa Y., Activity of a Neuron and Formulation of a Neural Group for Synchronized Systems, *International Journal of Biology and Biomedical Engineering*, Issue 2, vol. 6, pp. 149-156, 2012.

[9] Takizawa Y., Fukasawa A., Formulation of a Neural System and Analysis of Topographical Mapping in Brain, *International Journal of Biology and Biomedical Engineering*, Issue 2, vol. 6, pp. 157-164, 2012.

[10] Fukasawa A., Takizawa Y., Activity of a Neuron brought by Electro-Physical Dynamics, *International Journal of Mathematical Models and Methods in Applied Sciences*, Issue 8, Volume 7, pp. 737-744, 2013.

[11] Takizawa Y., Fukasawa A., Electrical Measurement Scheme of Liquid Boundaries in Active Neuron, to be published in *Proc. of International Conference on Health Science and Biomedical Systems*, Nov. 22, 2014.

[12] Fukasawa A., Takizawa Y., Aactivities of Neuron and Unicellular Organism for Positive Pulse generation, to be published on *Proc. of Int. Conf. on MMCTSE’14*, Nov. 28, 2014.

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