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ULTRASONIC TOMOGRAPHY SYSTEM IN LIQUID – GAS FLOW MONITORING

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Abstract. This research was carried out to measure two phase liquid – gas flow regime by using a dual functionality ultrasonic transducer. Comparing to the common separated transmitter – receiver ultrasonic pairs transducer, using dual functionality ultrasonic transceiver is capable to produce same measurement results hence further improvised and contributes to the hardware design improvement and system accuracy. Due to the disadvantages and the limitations of the separated ultrasonic transmitter – receiver pair, therefore this thesis presents a non-invasive of ultrasonic tomography system using ultrasonic transceiver as an alternative approach. By using 8 units of ultrasonic transceivers, the electronic measurement circuits, the data acquisition system and suitable image reconstruction algorithms, the measurement of a liquid/gas flow was realized. The system is capable of visualizing the internal characteristics of liquid and gas flow and provides the concentration profile for the corresponding liquid and gas flow. This system is useful in monitoring of liquid/gas flow in flow regime, chemical mixture transportation or fluid transportation at sub sea oil fields.

Keywords: Ultrasonic; tomography; flow system; liquid gas; transceiver

Abstrak. Suatu kajian proses tomografi ultrasonik telah dijalankan untuk mengenal pasti dan mengukur pengaliran dua fasa iaitu campuran fasa cecair dan gas. Sistem ini telah dibina menggunakan lapan unit penderia ultrasonik mempunyai dua fungsi (pemancar atau penerima isyarat) pada suatu masa. Berbanding dengan penggunaan penderia ultrasonik yang lazim digunakan, penderia ultrasonik dwi – fungsi ini mampu menberi pengukuran dan imej tomogram yang sama kualitinya malah ia mempunyai lebih banyak kelebihan dan lebih tepat. Disebabkan beberapa kebatasan penggunaan penderia ultrasonik yang berfungsi secara individu, kajian ini dijalankan supaya tidak mengganggu proses pengaliran aliran dalaman paip dan sebagai satu pendekatan alternitif menggunakan penderia ultrasonik dwi – fungsi tersebut. Dengan lapan unit penderia ini, litar – litar pengukuran, sistem perolehan data dan algoritma pembentukan imej yang bersesuaian telah direalisasikan. Keputusan yang diperolehi hasil dari kajian ini menunjukkan tomografi ultrasonik menggunakan penderia dwi – fungsi berjaya memaparkan ciri.

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– ciri dalamaan bagi pengaliran dua fasa ini iaitu cecair dan gas. Sistem sebegini sangat berguna dalam bidang campuran bahan cecair kimia atau penghantaran cecair di kawasan luar pantai

Kata kunci: Ultrasonik; tomografi; sistem pengaliran; cecair dan gas; penderia ultrasonik

1.0 INTRODUCTION

This research aims to develop a non-invasive ultrasonic tomography and to develop application to reconstruct image of the two phase liquid – gas flow program. Similar research in non-invasive method of ultrasonic tomogram fabrication technique was introduced [1]. No further improvement was done by later researches. The development on ultrasonic tomography has shifted to focusing on two-phase liquid – gas flow. This system implemented invasive method which is not appropriate practically in most industries [2].This system requires high excitation voltage (200V) to transmit ultrasonic signal via a transmitter. Such high voltage has many restrictions in safety wise and cost wise.

Common ultrasonic tomography system uses a separated type of ultrasonic transmitter and ultrasonic receiver with a specified frequency range. Such system will raise some difficulties such as:

(i) More space required to mount more sensors
(ii) More sensors will cost higher
(iii) Accuracy of the system will decrease

To overcome the above mentioned problems, this research will implement using ultrasonic transceiver to replace the use of separated ultrasonic transmitter – receiver pair. Hence, such system can improve the accuracy of measurement and uses less space compare to the separated transmitter – receiver pair.

2.0 ULTRASONIC TOMOGRAPHY

Ultrasonic sensor systems are based upon interactions between the incident ultrasonic waves and the object to be imaged.

In most non-destructive testing or medical applications, an object or field of interest is irradiated from a single viewpoint, usually with a narrow beam of ultrasonic acoustic energy. Some ultrasonic process tomography utilizes a wide beam angle beam as shown in Figure 2.0 and Figure 2.1 below.

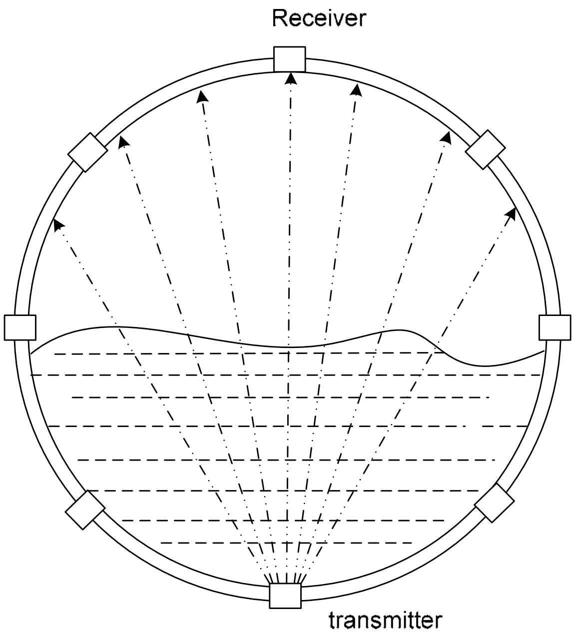


Figure 2.0 Wide beam projection

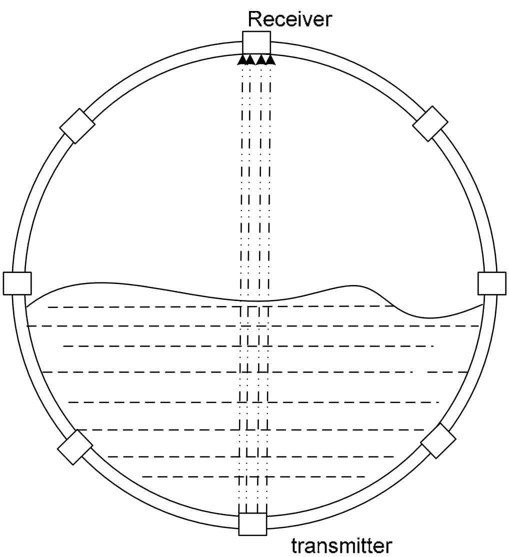


Figure 2.1 Narrow beam

Whether an ultrasonic beam is narrow or wide angel, it advances as a longitudinal wave front, in common with all sound waves.

Ultrasonic tomography technique is the use of ultrasound to detect the changes of acoustic impedance (Z) which is closely related to density (ρ) of the medium [3]. This can be a useful descriptor to identify the complex ratio of sound pressure to particle velocity which is analogous to electrical impedance. The acoustic equivalent to this relation is given by below equation [4].

$$Z = \rho\, c$$

where

Z = the acoustic impedance (kg/m^{2}s)
ρ = the density of the medium (kg/m^3)
c = the sound velocity in the medium (m/s)

The velocity of the sound value (c) thus complements other imaging technologies such as Electrical Capacitance Tomography (ECT) and Electrical Impedance Tomography (EIT). The value of the acoustic impedance for certain material depends on its physical properties and it is independent of the wave characteristics and its frequency. Acoustic impedance is important to:

(i) Determine the acoustic transmission and reflection at the boundary of two different materials.
(ii) To design the ultrasonic transducer.
(iii) The absorption assessment of sound in a medium such as solid, liquid or gas.

The greater the difference in acoustic impedance at interface, the greater will be the amount of energy reflected. Conversely, if the impedances are similar, most of the energy is transmitted.

To investigate the efficiency of ultrasound wave propagation in liquid or gas, below formula is calculated [5].

Reflection coefficient, $R = \frac{p_r}{p_e} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]$

Transmission coefficient, $D = \frac{p_d}{p_e} = \left[\frac{2Z_2}{Z_2 + Z_1}\right]$

where

p_e = the incident wave sound pressure
p_r = the reflected wave sound pressure

p_d = the transmitted wave sound pressure

The wave propagation energy transmission from pipe section to the liquid can be calculated as below:

$Z_1 = 3.2 \times 10^6$ kg/m^{2}s (Acrylic)
$Z_2 = 1.5 \times 10^6$ kg/m^{2}s (Water)

$$R_{(liquid\ /\ gas)} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right] = \left[\frac{430 - 1.5\times10^6}{430 + 1.5\times10^6}\right]$$

$$= -0.9994 \Rightarrow -99.94\%$$

$$D_{(liquid\ /\ gas)} = \left[\frac{2Z_2}{Z_2 + Z_1}\right] = \left[\frac{2\times430}{430 + 1.5\times10^6}\right]$$

$$= 0.0006 \Rightarrow 0.06\%$$

From above calculation, more than half of the wave propagation energy able to transmit through the pipe-section and liquid boundary which is 63.83% the rest 36.17% is reflected due to its impedance. This means ultrasound wave could penetrate through the acrylic pipe material. The receiver will be able to response to the incoming signals.

3.0 HARDWARE SYSTEM

Ultrasonic transceiver is a type of transducer that converts electrical energy into high frequency sound waves and also converting sound waves back to electrical energy. It contains piezoelectric crystal materials that have the ability to transform mechanical energy into electrical energy and vice versa [6]. Below Figure 3.3 shows the transceiver sensor used in this research.

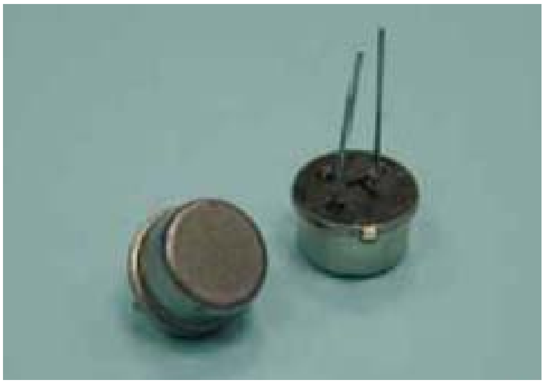


Figure 3.0 Ultrasonic transceiver sensor

This sensor is suitable for non-invasive measurements and it is low cost. Its flat main surface makes it easy to be mounted on acrylic pipe. Transceivers can be set as transmitter or receiver by using a suitable analog switching device such as SPDT Quad switches ADG333A as shown in below Figure 3.1.

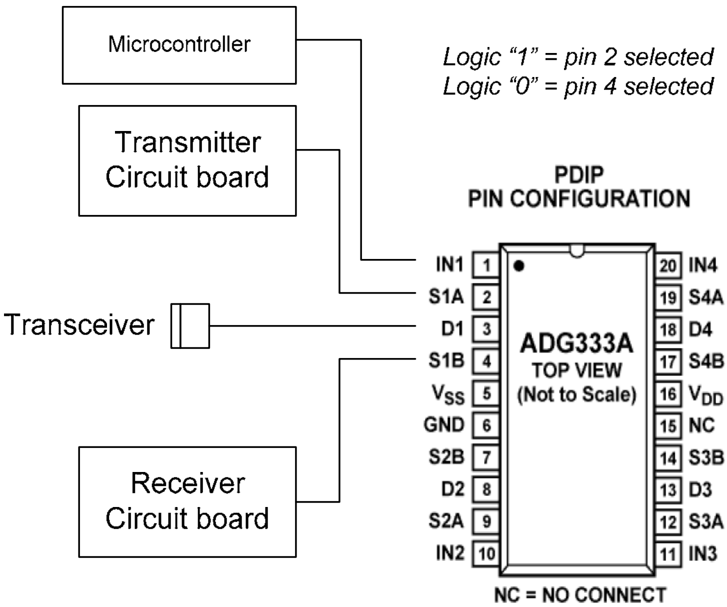


Figure 3.1 Analogue Switching Device Configuration

This analogue switches can be control by injecting a logic "1" or logic "0" via a microcontroller into an analogue switch. By default, the switching logic can be illustrated in below Table 3.0.

Table 3.0 SPDT Quad analogue switch truth table

Logic	Switch A	Switch B
0	OFF	ON
1	ON	OFF

From above Figure 3.1, the analog quad switch can be use to control the switching of transceivers. This can be done by giving logic "1" or "0" to switch between transmitter circuit and receiver circuit. It can only function as transmitter or receiver at one time. With the use of transceiver, better imaging can be reconstructed also transducers configuration is the key factor in the efficiency of data acquisition [7] where image reconstruction process comes next.

The ultrasonic transceivers are firmly mounted on the acrylic pipe surface. This is done by using a sensor jig to hold firm it [8]. All sensors are evenly placed to ensure better receiving signal can be captured. Correct and precise positioning of sensors is crucial to obtain accurate results. The sensor configuration of the sensors is as below Figure 3.2 while Figure 3.3 shows the acrylic pipe hardware design.

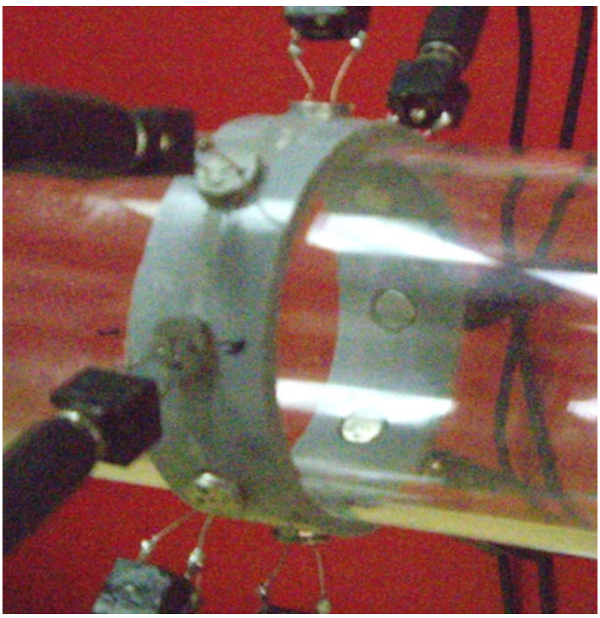


Figure 3.2 Sensor jig design

Figure 3.3 Acrylic pipe hardware design

4.0 SOFTWARE SYSTEM

The ultrasonic transmitter requires pulse tone to transmit signals. This is done by generating 40 kHz pulse wave via microcontroller [9].Pulse wave are sent to all 8 channels via Port B of the microcontroller which has exactly 8 pins.

The transmitted 40 kHz pulse wave response is shown in Figure 4.0 below. These pulse causes transmitter to vibrate and produce sound wave at 40 kHz to a located receiver.

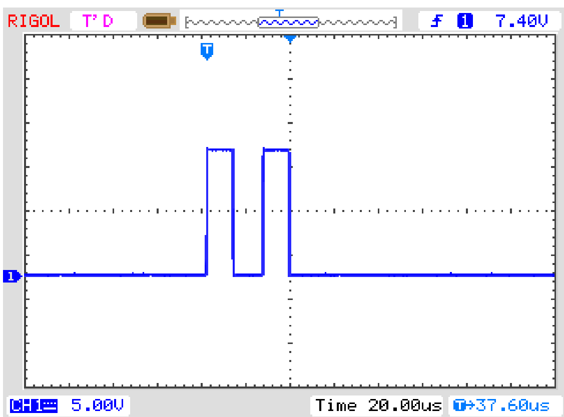


Figure 4.0 40 kHz pulse signal

The transmitted ultrasound wave can be captured by the transceiver which is switched to receiver mode. The captured acoustic wave response is shown in below Figure 4.1.

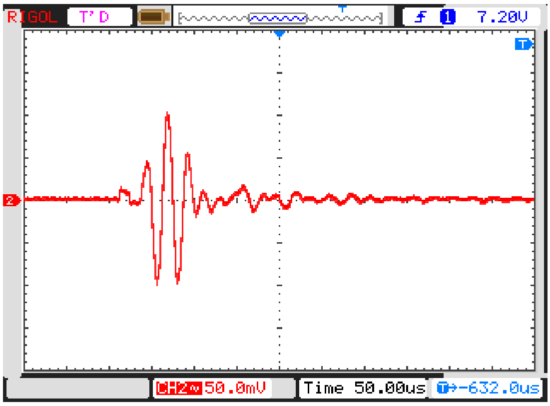


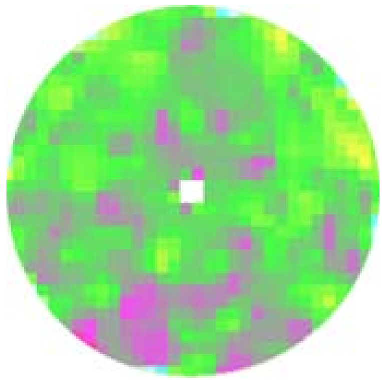
Figure 4.1 Response signal at receiver

5.0 RESULTS AND DISCUSSION

The liquid – gas flow regime is identified by placing the experimental acrylic pipe horizontally such that the gas phase (air) flows in the upper section of the pipe and the liquid (tap water) in the lower section. Horizontal pipe with static liquid model was us and empty air is use to carry out measurement on two phase liquid – gas flow. Four types of measurement carried out as shown in below:

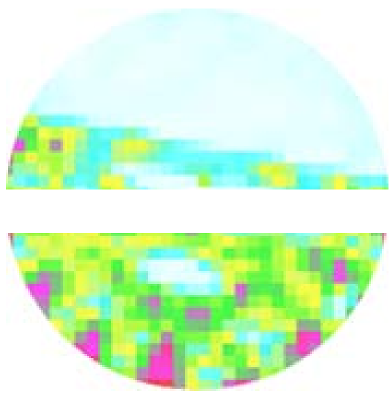
(i) Full flow
(ii) Three quarter flow
(iii) Two quarter flow
(iv) One quarter flow

The final reconstructed tomogram images are shown as below Figure 5.0 in four types of measurement as mentioned above.



(a) Full flow image

(b) Three quarter image



(c) Two quarter image

(d) One quarter image

Figure 5.0 Four types of measuremen

By observing the experimental reconstructed images, the back projection technique results in blurring the object image. The blurring is due to the projection along straight lines and the smearing effect. The distribution of the intensity is centre symmetrical and dependent on the projection angle where the blurring function is inversed of the corresponding pipe radius.

One of the methods to reduce the blurring is by using the Hybrid Binary Reconstruction Algorithm (HBRA). This algorithm has the advantage of correcting and improving the stability and repeatability of the reconstructed images [10]. This procedure is only appropriate for two-phase flow imaging in cases where the phases are well separated such as liquid-gas flow [11].

6.0 CONCLUSION

This research shows that this system is able to detect the presence of two phase liquid – gas flow in pipeline. From the image result which has successfully generated, the use of only 8 transceivers can produce same result as 16 pairs of separated transmitters – receivers. The separate ultrasonic transmitter-receiver transducer which is commonly used in ultrasonic tomography research requires larger spaces to mount it on the surface of the pipelines. This is due to the needs of having extra pairs of transmitter – receiver where each of these transmitters – receiver pairs has only single function either to transmit or receive only. Comparing to the use of transceivers, 8 units of ultrasonic transceivers could perform measurements as the performance of 16 pairs separated transmitters – receivers.

REFERENCES

[1] Gai H., Y. C. Li, A. Plaskowski, and M. S. Beck. 1989. Flow Imaging Using Ultrasonic Time-Resolved Transmission Mode Tomography. Proc. IEE 3rd Int. Conf. Image Processing and Its Application. 237-241.

[2] Sanderson, M. L. and Yeung, H. 2002. Guidelines for the Use of Ultrasonic Non-invasive Metering Techniques. *Flow Measurement and Instrumentation*. Elsevier. 13: 125-142.

[3] Hoyle, B. S. 1996. Process Tomography using Ultrasonic Sensor. *Meas. Sci.Technol*. 7: 272-280.

[4] Williams, R. A. and Beck, M. S. (Eds). *Process Tomography: Principles, Techniques and Applications*. Oxford: Butterworth-Heinemann. 101-117.

[5] Krautkramer, J. and Krautkramer, H. 1990. *Ultrasonic Testing of Materials*. 4th Edition. New York: Springer-Verlag.

[6] Alfredo Vázquez Carazo. 2000. *Novel Piezoelectric Transducers for High Voltage Measurements*. Universitat Politècnica de Catalunya. 242.

[7] Al-Salaymeh, A. and Durst, F. 2004. Development and Testing of a Novel Single-Wire Sensor For Wide Range Flow Velocity Measurements. *Measurement Science Technology*. 15: 777-788.

[8] Henriksen, E. Karl .1973. *Jig and Fixture Design Manual*. Industrial Press. 1.

[9] Fazalul Rahiman, M. H., Abdul Rahim R., Mohd Hezri Fazalul Rahiman, and Mazidah Tajjudin, 2006. Ultrasonic Transmission-Mode Tomography Imaging for Liquid/Gas Two-Phase Flow. *IEEE Sensors Journal*. 6: 6.

[10] Fazalul Rahiman M. H. and Abdul Rahim R. 2008. A Novel Hybrid Binary Reconstruction Algorithm for Ultrasonic Tomography. *Sensors & Transducers Journal*. 8(3): 93-100.

[11] Plaskowski, A., Beck, M. S., Thron, R., Dyakowski, T. 1995. *Imaging Industrial Flows: Applications of Electrical Process Tomography*. U.K.: IOP Publishing Ltd.