WATER AND OIL FLOW REGIME IDENTIFICATION USING TRANSMISSION-MODE ULTRASONIC TOMOGRAPHY

MUHAMAD AHNAF BIN MOHD ABD. GHAFAR

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Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang

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ABSTRACT

The purpose of this project is to develop a suitable ultrasonic tomography system that can identify two phase flow regime. By using ultrasonic, emphasis is placed on the evaluation of its performance in flow regime identification and cross-sectional measurement. The transmission-mode approach has been used for sensing the water and oil two-phase flow. The transmission mode for sensing purpose was implemented where 4x4 projections is produced. This is one of the non-invasive methods that do not disturb the internal flow of the pipeline, hence, water and oil flow inside the pipe could be monitored by this system in an uninterrupted manner and flow regime determined based on the sum of all the sensor's values. Analysis and result measurement was using oscilloscope are presented.

ABSTRAK

Tujuan projek ini adalah untuk membangunkan sistem tomografi ultrasonik yang boleh mengenal pasti dua fasa aliran komposisi. Dengan menggunakan pendekatan ultrasonik, penekanan diletakkan pada penilaian prestasi dalam aliran komposisi aliran pengenalan dan pengukuran keratan rentas. Mod penghantaran terus telah digunakan untuk mengesan air dan minyak aliran dua fasa. Mod penghantaran terus pengesanan yang dilaksanakan menghasilkan unjuran 4x4. Ini adalah salah satu kaedah yang bukan invasif yang bermaksud tidak mengganggu aliran dalaman paip, oleh itu, air dan aliran minyak di dalam paip boleh dipantau oleh sistem ini dengan cara yang tidak terganggu dan regim aliran ditentukan berdasarkan jumlah semua sensor nilai-nilai. Pengukuran dan hasil analisis menggunakan osiloskop.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

c	–	Velocity
f	–	Frequency
λ	–	Wavelength of ultrasound
ρ	–	Density
R	–	Reflection Coefficient
T	–	Transmission Coefficient
Z	–	Acoustic Impedance
V_{ref}	–	Reference Voltage
Tx	–	Transmitter
Rx	–	Receiver
V	–	Volt(s)
Vp-p	–	Peak to peak voltage

CHAPTER 1

INTRODUCTION

1.1 An Overview of Process Tomography

An identical meaning of word 'tomography' came from the Greek words 'tomos' meaning 'to slice' and 'graph' meaning 'image' (Yasmin, 2009). Hence, process tomography knew as a process of obtaining the plane-section images of a three-dimensional object. Applying this process techniques produce cross-section images of the flow composition in a pipeline, thus, propose great potential for the development, and verification of flow models, and also for process diagnostic.

Constructed tomography gives impressive information that can be used, commonly, in the design and control of processes. The operation and design of processes dealing multi-composition phases become easier by differentiated compositions in a process to be imaged in real-time or offline system using non-destructive sensors (Hafiz, 2009). Vector velocity and component concentration distribution in periphery-type pipelines will be determined from the constructed tomogram due information on the flow regime.

Despite their popularity is widely used in industry, tomographic imaging has actually been introduced in medicine field a few recent decades. A number of applications of tomographic imaging of process equipment were described in the 1970s but generally these involved using ionizing radiation from X-ray or isotope sources (Ng Wei Yap, 2005). However, this approach does not satisfactorily meet the requirements for cost and safety factors. Optical tomography is an attractive method since it may prove to be less expensive, have a better dynamic response, and more portable for routine use in process plant other than radiation-based tomographic methods such as positron emission, nuclear magnetic resonance, gamma photon emission and x-ray tomography. Its performance is also independent of temperature, pressure and viscosity of fluid (Mustafa, 2008).

1.2 Importance of Study

The technology of ultrasonic sensor has widely used especially in heavy industry such as palm oil, petroleum and chemical industry. Industry need to utilize resources more efficiently and to satisfy demand and legislation for product quality and reduced environmental emissions. Therefore, engineer has discovered one of the non-invasive techniques that can be used in the industry for monitoring the flow composition of two liquids flow such as water and oil in vessel or pipe. Known as ultrasonic tomography, this method can encounter conventional monitoring measuring instrument that may be unsuitable to be exposed to the harsh internal condition.

Ultrasonic sensor is a kind of non-destructive sensor and has been successfully applied in process measurement particularly in flow measurement. Moreover, this monitoring system does not disturb the internal flow of the pipe. Ultrasonic technology provides the means to obtain quantitative, highly accurate and reliable inspection data. The installation of the ultrasonic tomography system also does not require the shutdown of the industry’s process. Thus, it also makes installation easier and portable convenience.

The purpose of this project is to develop a suitable ultrasonic tomography system that can identify two phase flow regime composition of the water and oil. Transmission-mode sensing method is implemented by using 4x4 projections which are 4 transmitters and 4 receivers of ultrasonic sensors. This project is divided into two parts which are hardware and software. Collected data from the hardware will be analysis and calculated.

1.3 Background Statement

In general, we know that a lot of pipes and vessel channels used in industrial processes. This is very complicated of a monitoring system to identify flow composition inside the pipeline and vessels. Thus, reliable systems have to be developed whereby the system is able to view objects within these pipes without interrupting the flow. The process tomography system requires the knowledge of various disciplines such as instrumentation process, and optics to assist in the design and development of the system (Mustafa, 2008). An ultrasonic tomography is one of the non-destructive techniques that have been successfully used in industries in order to monitor and identify the actual process flow inside pipelines and vessels by not interrupting the process. Despite this method has been popularly used, many researchers focus on the output tomogram produced for analysis regardless of the physical structure of the examined pipeline. The way to analyze the result also is emphasized for the production of accurate analysis. Although this project is far from perfect compared to previous research, but with a focus on how to analyze the tomogram will be the benchmark of this project that may be used for future research.

1.4 Objective of Project

The objective of this project is to develop a suitable ultrasonic tomography system that can identify water and oil flow regime using transmission-mode ultrasonic sensing method.

1.5 Scope of Project

There are several scopes that involve in this project;

i. To determine the composition of water and oil flow by implementing the transmission-mode of ultrasonic tomography.
ii. To design the simple circuit of ultrasonic tomography system.
iii. To implement transmission-mode sensing method of 4x4 projections.
iv. To implement microcontroller to project and controller a sign of ultrasound.

1.6 The Thesis Outline

This thesis consists of seven chapters. Chapter 1 gives a brief introduction to process tomography follow by project background, background statements, objective of the project and scope of the study.

Chapter 2 mainly discusses the literature review about ultrasound architectures. It consists of an overview of process tomography, the significance of developing the system, types of tomography and a historical review about the evolvement of the process.

Chapter 3 describes the methodology of the project itself. The hardware development process and way to analyze the output that implement in this project was presented and explained detail.

Chapter 4 presents the results obtained from the experiments done on the developed system. The results obtained are discussed and a conclusion was drawn based on the analysis.

Chapter 5 is written to discussing the conclusion and the recommendations on matters that can improve the research project in the near future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Ultrasound

Ultrasounds known as sound with frequency that above 20 kHz. Ultrasound behaves in a similar manner with audible sound, but it has much shorter wavelength. This means that it can be reflected by very small surfaces such as defects inside the materials. It is because of this that makes the ultrasound useful for non-destructive testing of materials. Figure 2.1 shows the classification of sound due range frequency meanwhile; Figure 2.2 shows the application of ultrasound at different frequencies.

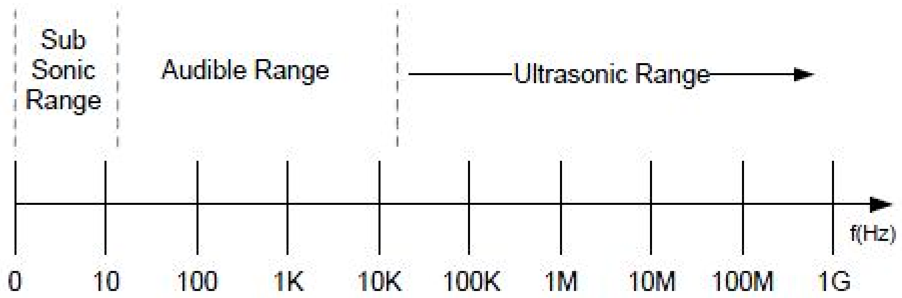

Figure 2.1: Sound classification due range frequency

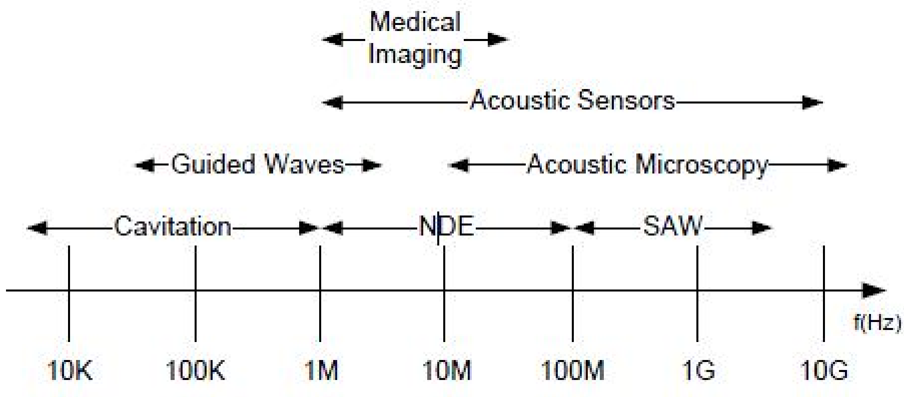

Figure 2.2: Application of ultrasound at different frequency

2.2 Fundamental of Ultrasound

There are several fundamentals of ultrasound that need to be known before it is intended to be applied in non-destructive or non-invasive tomography testing. Ultrasound travels in the form of a wave, similar to the way light travels. However, unlike light waves, which can travel in vacuum, ultrasound requires elastic medium such as solid and liquid to travel (Ng Wei Nyap, 2005).

Regarding propagation of ultrasound, ultrasonic testing is based on time-varying deformations or vibrations in material, which is referred as acoustics (Ruzairi, 2007). Acoustics behaviour can describe as it focus on particles that contain many atoms that move in unison to produce a mechanical wave. There are several types of waves that need to be known before carry on the ultrasonic testing such as longitudinal waves, transverse (shear) waves, surfaces-Rayleigh and many more. Usually, longitudinal and transverse waves were selected to use widely on ultrasonic testing (Yasmin, 2009). Figure 2.3 and figure 2.4 explain the direction of both longitudinal and transverse wave propagation.

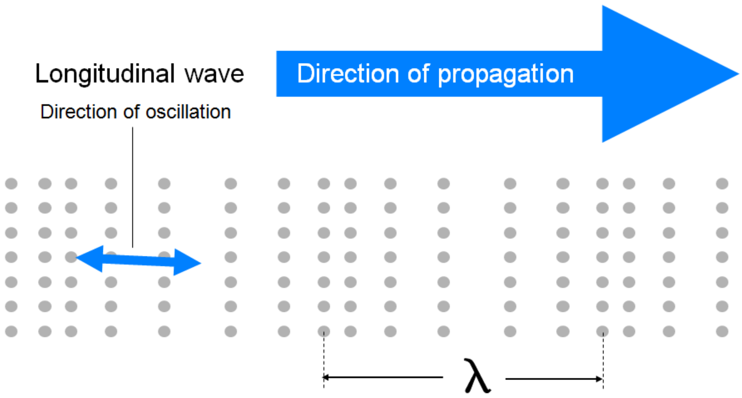

Figure 2.3: Propagation of longitudinal wave

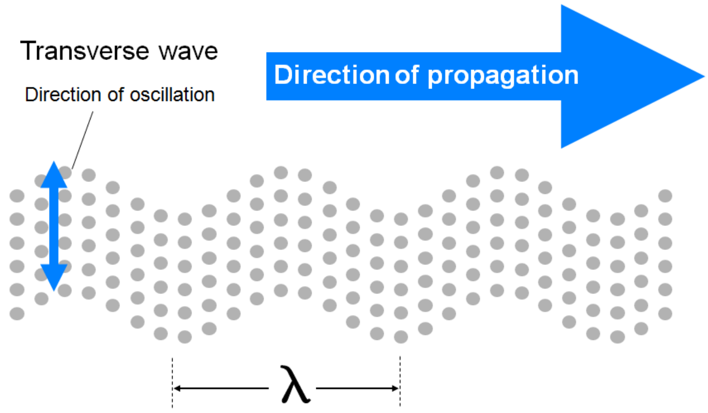

Figure 2.4: Propagation of transverse wave

2.3 Piezoelectric Effect

Ultrasonic transducers commonly use an ultrasound physic principle so-called piezoelectric effect to convert electrical energy into mechanical movement despite of applying number of principles that used to generate ultrasound, which was discovered by Pierre and Jacques Curie in 1880 (Yasmin, 2009).

Piezo by definition knew as pressure, so piezoelectric means that pressure-based electrical energy generated is applied to a quartz crystal. When electrical energy is applied to the face of the crystal, the shape of the crystal changes as a function of the polarity due to applied electrical energy. As the crystal expands and contracts it produces compressions and rarefactions, and creates sound waves. Figure 2.5 and figure 2.6 explained the effect of piezoelectric effect due to quartz crystal.

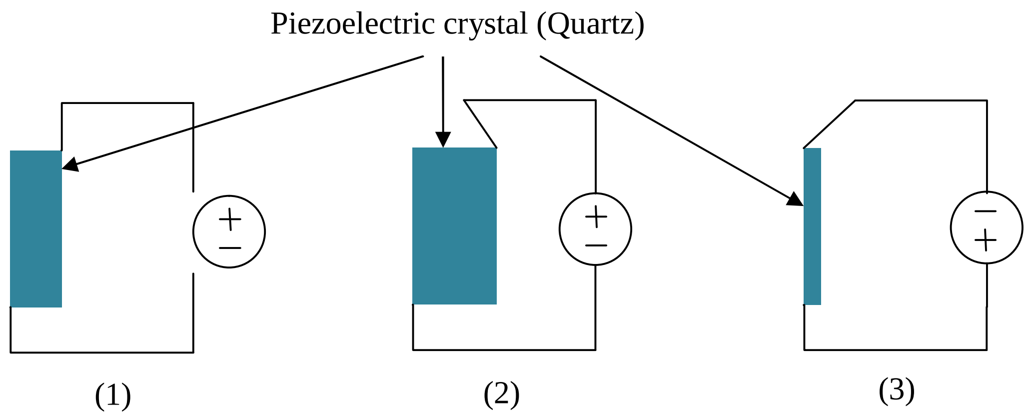

Figure 2.5: (1) Piezoelectric crystal remains at normal shape without giving any electricity supply. (2) The crystal gets thicker, due to a distortion of the crystal lattice. (3) The effect inverses with polarity change

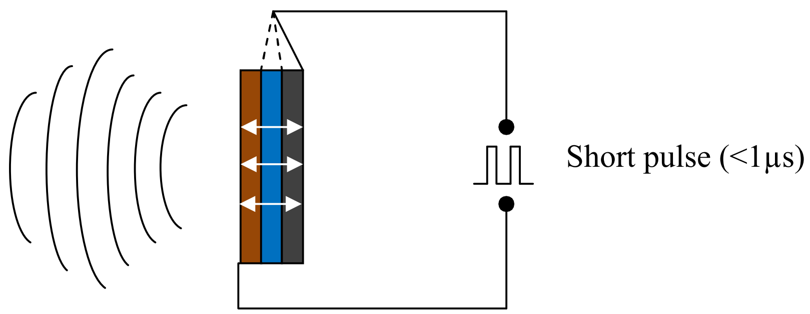

Figure 2.6: A short voltage pulse generates an oscillation at the crystal‘s resonant frequency

The piezoelectric effect is a reversible process as it can produce a pulse of analogues electrical energy by mechanically exciting the crystal as occur at ultrasonic receiver.

2.4 Frequency, Period and Wavelength of Ultrasound

The wavelength, λ is the length of a complete cycle for ultrasound while the period, *T* is the time taken to complete a full cycle of ultrasound and measure in second. The frequency, *f* is the number of cycle completed in second, s or measured in hertz, Hz (Yasmin, 2009). The relation of wavelength, λ and period, T in continuous wave or sinusoidal wave shows as in Figure 2.7.

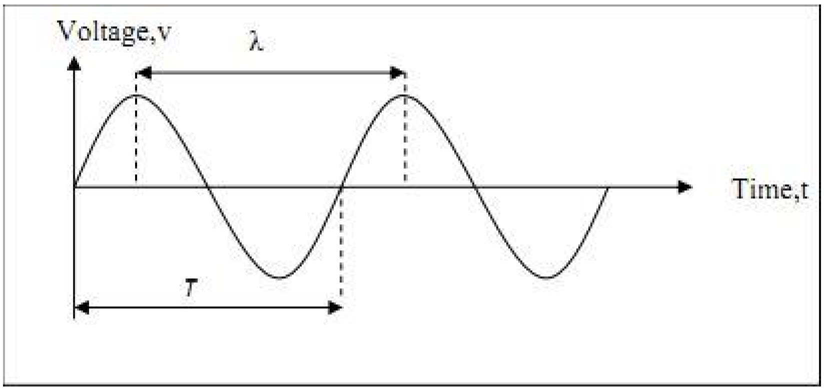

Figure 2.7: Continuous wave of ultrasound

The relation between frequency,*f* and period,T of a continuous wave of ultrasound is given by equation 2.1.

$$f = 1/T \qquad \text{....... (Eq.2.1)}$$

The relation between velocity,c , frequency, *f*, wavelength,λ and period,T is given by equation 2.2 and equation 2.3.

$$\lambda = c/f \qquad \text{....... (Eq.2.2)}$$

$$\lambda = cT \qquad \text{....... (Eq.2.3)}$$

2.5 Acoustic Impedance

A term that is used to describe the interaction of ultrasound with a material is called acoustic impedance; z which is analogous to electrical impedance is equal to the product of density, ρ and speed of sound, c (Ruzairi, 2007). 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 (Ruzairi, 2005). Thus, we can simplify that the difference in acoustic impedance at interface proportional to the amount of energy reflected. The equation 2.4 shows the relation between acoustic impedance, z, and product of density, ρ and speed of sound, c.

$$Z = \rho c \qquad \text{……. (Eq.2.4)}$$

There are several factors explaining the importance of the acoustic impedance such as to determine the different of acoustic transmission and reflection at boundary between two materials, to design ultrasonic transducers and assessing absorption of sound in a medium (Yasmin, 2009).

Table 2.1 shows the acoustic impedance of several materials that used as experimental medium.

Table 2.1: Acoustic impedance of experimental materials

Medium	Material	Acoustic Impedance, Z (kg $m^{-2}s^{-1}$)
Experimental column	PVC	$3.27x10^6$
Liquid	Water	$1.50x10^6$
Liquid	Palm oil	$1.35x10^6$

The reflection and transmission coefficients are given as equation 2.5 and equation 2.6 by considering the behaviour of a normal ultrasonic wave at an interface.

$$\text{Reflection coefficient, R} = \frac{\rho_r}{\rho_e} = \left[\frac{z_2 - z_1}{z_2 + z_1}\right] \quad \text{....... (Eq.2.5)}$$

$$\text{Transmission coefficient, T} = \frac{\rho_t}{\rho_e} = \left[\frac{2z_2}{z_2 + z_1}\right] \quad \text{....... (Eq.2.6)}$$

Value of acoustic impedance is too important in order to determine the transmission and reflection of the ultrasonic propagation in all materials. Figure 2.8 and 2.5.2 explains the propagation of the ultrasonic wave occurred.

i) Propagation of the ultrasonic wave between PVC pipe to water media.

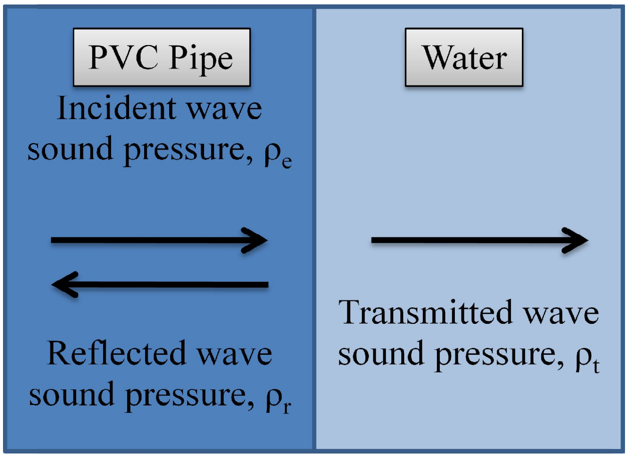

Figure 2.8: Ultrasonic propagation from PVC pipe to water medium

Refers to the experiment conducted, the acoustic impedance of material used for PVC pipe, z_1 = 3.27x10^6 kg m^{-2}s^{-1} and for water, z_2 = 1.50x10^6 kg m^{-2}s^{-1} , thus, by using equation 2.7 and 2.8, the calculation to determine R and T present as below:

$$R_{(PVC\,/\,Water)} = \left[\frac{1.50\times10^6 - 3.27\times10^6}{1.50\times10^6 + 3.27\times10^6}\right] = -0.3712 = 37.12\% \quad \text{....... (Eq.2.7)}$$

$$T_{(PVC\,/\,Water)} = \left[\frac{2(1.50\times10^6)}{1.50\times10^6 + 3.27\times10^6}\right] = 0.6289 = 62.89\% \quad \text{....... (Eq.2.8)}$$

From equation 2.7, the reversal of the phase relative occurs due to negative sign of reflection coefficient value calculated (Yasmin, 2009), mean that 37.12% of wave reflected in medium water.

ii) Propagation of the ultrasonic wave between water to oil media.

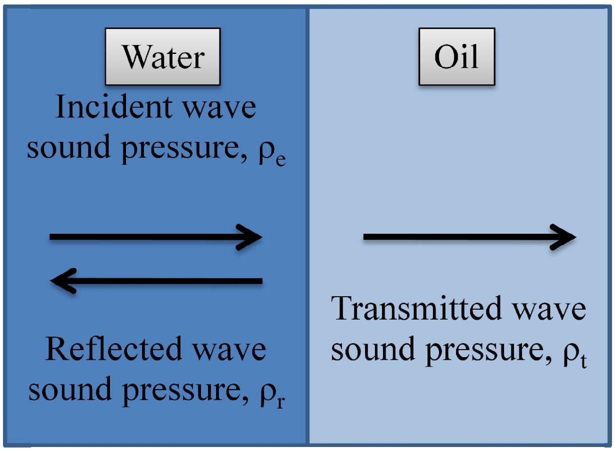

Figure 2.9: Ultrasonic propagation from water to oil medium

The acoustic impedance of material used for water, $z_1 = 1.50\text{x}10^6$ kg $m^{-2}s^{-1}$ and for oil, $z_2 = 1.35\text{x}10^6$ kg $m^{-2}s^{-1}$, thus, by using equation 2.9 and 2.10, the calculation to determine R and T present as below:

$$R_{(Water\,/\,Oil)} = \left[\frac{1.35\times10^6 - 1.50\times10^6}{1.35\times10^6 + 1.50\times10^6}\right] = -0.0526 = 5.26\% \quad \text{....... (Eq.2.9)}$$

$$T_{(Water\,/\,Oil)} = \left[\frac{2(1.35\times10^6)}{1.35\times10^6 + 1.50\times10^6}\right] = 0.9474 = 94.74\% \quad \text{....... (Eq.2.10)}$$

The ultrasonic wave almost reflected when it propagates into the PVC pipe as it penetrated to PVC surface which is 37.12%. Propagation of ultrasonic wave from water into oil get less reflection which is 5.26% and the transmission of wave was being smooth which is 94.74%.