

Ultrasonic Tomography - Water and Oil Flow Monitoring System

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ABSTRACT

A monitoring system for water and oil flow using ultrasonic Tomography is implemented. Information such as the type of flow, the composition of the water and oil can be obtained from the system. The composition of the flow is determined based on the propagation time of the ultrasonic waves. The ultrasonic Tomography system includes the sensors fixture design, signal conditioning circuits and image reconstruction software. The image reconstruction algorithm that used is the Linear Back Projection (LBP) algorithm.

Keywords: ultrasonic Tomography, image reconstruction, water and oil, monitoring system

1. Introduction

Ultrasonic testing is based on time-varying deformations or vibrations in material, which is referred to acoustics [15]. All material substances are comprised of atoms, which may be forced into vibration motion about their equilibrium positions. Acoustics is focused on particles that contain many atoms that move in unison to produce a mechanical wave. If the material is not stressed in tension or compression beyond its elastic limit, its individual particles will perform elastic oscillations. When the particles of a medium are displaced from their equilibrium positions, internal forces arise. It is these elastic restoring forces between particles, combined with inertia of the particles that leads to oscillatory motions of the medium [3]

In solids, several types of wave propagation can occur that are based on the way the particles oscillate [16]. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear waves is shown in Figure 1.

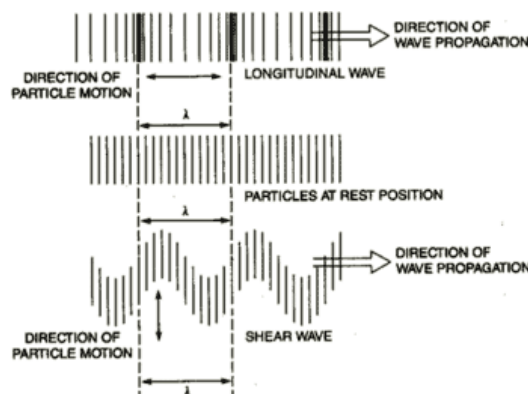


Figure 1. Propagation of ultrasonic waves

In longitudinal waves, the oscillations occur in the longitudinal direction or the direction of wave propagation. Longitudinal waves can be generated in liquids, as well as solids because the energy travels through the atomic structure by a series of compression and expansion movements.

In the transverse or shear wave, the particles oscillate at a right angle or transverse to the direction of propagation. Shear waves require an acoustically solid material for effective propagation and, therefore, are not effectively propagated in materials such as liquids or gasses [15]. Shear waves are relatively weak when compared to longitudinal waves. The kind of waves that involved in this system is the longitudinal wave as the flow medium is comprised of liquids. The measurement involved the propagation time of the ultrasonic wave.

2. Ultrasonic Time of Flight Method

Ultrasonic sensor is a kind of non-destructive sensor and has been successfully applied in process measurement particularly in flow measurement [1]. There are three sensing modes of ultrasonic Tomography which are transmission, reflection and diffraction sensing modes.

The method that applied in this research is the transmission method. In this method, the propagation time of the ultrasonic wave from the transmitter to the receiver through the medium will be measured. The velocity of the ultrasonic wave varies in different mediums. Different composition of two liquids such as water and oil will also show different propagation time of ultrasonic wave[2] By finding the difference of this propagation time, ultrasonic Tomography could be applied for the flow monitoring purpose. Table 1 shows the velocity of ultrasonic wave in certain medium:

In ultrasonic Tomography, the required equipments include ultrasonic generator, transducers to transmit and receive ultrasonic waves as well as computerized image-processing system.

Table 1. Velocity of ultrasonic wave in different mediums

Material	Longitudinal wave velocity, c (m s^{-1})	Density, ρ (kg m^{-3})	Acoustic impedance, ρc ($\text{kg m}^{-2} \text{s}^{-1}$)
Glycerol	1900	1260	2.4×10^6
Lubricating oil (typical values)	1400	800	1.1×10^6
Olive oil	1400	900	1.3×10^6
Water	1500	1000	1.5×10^6
Air	330	1.3	430
Hydrogen	1300	0.90	110
Oxygen	320	1.4	450

3. Hardware implementation

The Figure 2 below shows the layout design of the ultrasonic Tomography system. There are 16 pairs of transmitters and receivers mounted non-invasively around the pipe. The diameter of the pipe used is 100mm. The flow inside the pipe is a mixture of water and oil. The composition of the flow that varies from time to time is monitored by this system.

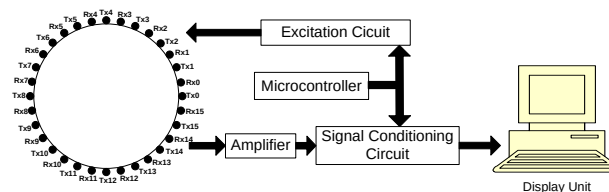


Figure 2. Layout design of ultrasonic Tomography

3.1 Fabrication of ultrasonic sensors

The design of sensor's fixture includes the clamping structure of the sensors around the pipe and the arrangement of the sensors. The ultrasonic sensors are mounted using couplant such as grease.

3.2 Circuits design

The circuits for the system are comprised of the excitation circuit and signal conditioning circuit. The excitation circuit provides pulses of $30V_{p-p}$ to the transmitter to transmit the ultrasonic wave.

The purpose of the signal conditioning circuit is to measure the time of flight (TOF) of the ultrasonic wave as shown in Figure 3. The signals received will be amplified first. Then, the first arriving ultrasonic signal is detected. The propagation time of the ultrasonic wave from the transmitter to the receiver is measured using binary counters inside the signal conditioning circuit.

The outputs from the counter are read by using data acquisition card. The interfacing between the hardware with the computer is also achieved through this data acquisition card.

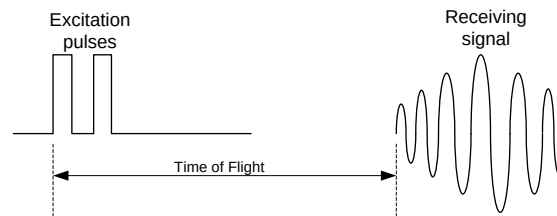


Figure 3. Time of flight measurement

4. Software implementation

A custom program is created using Visual Basic 6.0 for analyzing the composition. The image reconstruction algorithm that used is the linear back projection (LBP) algorithm. The linear back projection algorithm is actually based on the linearization of a normalized form of the original problem.

The linear back projection method could be represented by the mathematical equation [4] as below:

$$g \approx R\lambda \quad (1)$$

where R is an $(M \times N)$ matrix that represents the direct mapping of the problem and is called the projection matrix. The vector g contains data measured externally by the sensors while the vector λ is a set of unknown coefficients that characterizing the instantaneous cross section.

An image representing the cross section of the pipe is achieved using this algorithm. Distribution of the two components of the flow could be observed from the image.

5. Experiment and discussion

Different composition of water and oil flow is used for testing the ultrasonic Tomography system. Analysis is then done on the measurement acquired

However, there are a few assumptions made when the measurements are taken as below:

- i) The temperature in the laboratory is constant while the experiment is being carried out. Therefore, the measurement of the propagation time of the ultrasonic wave is not affected by the variation of temperature.
- ii) There are no bubbles in the mixture of water and oil flow. So, the reflection which caused by the bubbles is ignored. If bubbles are present in the flow, the transmission of the ultrasonic wave will be affected.
- iii) The wave length of the ultrasonic wave is assumed much longer than the water and oil fractions. So, the diffraction effect is also ignored.
- iv) Straight ray is assumed for the propagation path of the ultrasonic waves.

The measurement shows that the propagation time of the ultrasonic wave is different for different composition of water and oil. The image constructed could show the distribution of the water and oil components. Finally, composition of the flow could be found through the analysis of the image.

In order to improve the quality and accuracy of the image, other image reconstruction algorithm such as filtered back projection algorithm, convolution back projection algorithm should be investigated.

6. Conclusion

The main objective of this research is achieved. The ultrasonic Tomography system can be used for the water and oil flow monitoring purpose. However, further improvement of the system need to be done by implementing the reflection method as well. Better image reconstruction algorithm also needs to be investigated.

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