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Determination of Water and Oil Flow Composition Using Ultrasonic Tomography

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Abstract: This paper presents an investigation into the application of an ultrasonic tomography system to determine the composition of water and oil flow. There are three modes of the ultrasonic tomography system, the transmission mode, reflection mode and the diffraction mode. In this research, the ultrasonic tomography system using the transmission mode was implemented. This method is also 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 the composition of the flow is determined based on the sum of all the sensor's values. In this paper, the implementation method of the research is described and the acquired results are presented.

Keywords: Process tomography, transmission mode, Ultrasonic, Ultrasonic tomography, Water and oil flow.

1. INTRODUCTION

In the late 1980s and early 1990s, various studies have been carried out to investigate the component concentration in various flows by applying the capacitance tomography (ECT). This was due to the energy resource requirements, especially for measurements in the oil industry in Europe and the coal industry in the USA. Some of the studies include measurement of water content in oil [2] and the visualization of component distribution in multi-components flow pipelines [3]. In this research, different approached were implemented by using the ultrasonic sensor.

Ultrasonic sensor is a kind of non-destructive sensor and has been successfully applied in process measurement particularly in flow measurement [4]. An Ultrasonic tomography system is based upon interaction between the incident ultrasonic waves (frequency of 20 KHz to 10 MHz) [6] and the object to be imaged. In the transmission mode, the ultrasonic wave will propagate from one transmitter to the other receiver at the far end of the pipe, assume that the propagation of the ultrasound is a straight line is made. If the ultrasound passes through strongly inhomogeneous parts of the flow, then large errors may result. In this case, this mode would probably not suitable for the flow with large difference in acoustic impedance such as the water and bubble flow.

2. PRINCIPLES

The basic principles that are used in the research involved the acoustic impedance, propagation and attenuation of the ultrasound.

2.1 Propagation of Ultrasound

Ultrasonic testing is based on time-varying deformations or vibrations in material, which is referred as acoustics [5]. Acoustics is focused on particles that contain many atoms that move in unison to produce a mechanical wave.

Several types of wave propagation can occur that are based on the way the particles oscillate [7]. 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.

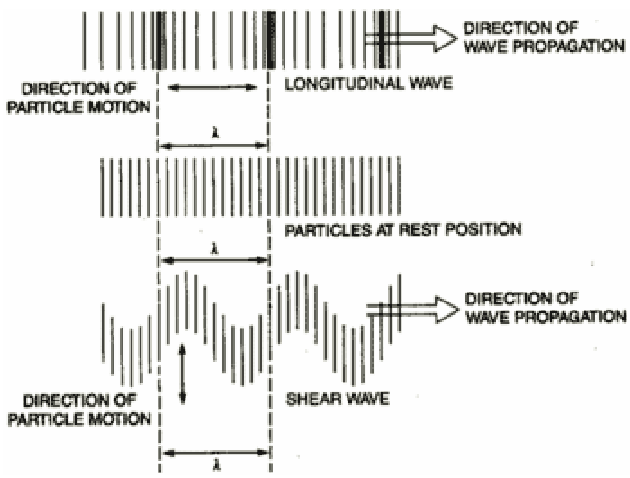


Figure 1. Propagation of longitudinal and shear waves

2.2 Acoustic Impedance

A term that is used to describe the interaction of ultrasound with a material is called acoustic impedance, *z* [8] which is analogous to electrical impedance and isequal to the product of density (p) and speed of sound (c). The equation is given as follows:

$$z = pc$$

If the difference in impedance at the interface is greater, the amount of energy reflected will also be greater. Table 1 shows the acoustic impedance of some materials.

Table 1. The acoustic impedances for some materials

Material	Longitudinal wave velocity,c ($m\ s^{-1}$)	Density,p ($kg\ m^{-3}$)	Acoustic impedance, pc ($kg\ m^{-2}\ s^{-1}$)
Aluminum	6400	2700	1.7×10^7
Steel	6000	7800	4.7×10^7
Glycerol	1900	1260	2.4×10^7
Lubricating oil	1400	800	1.1×10^7
Olive oil	1400	900	1.3×10^7
Water	1500	1000	1.5×10^7
Air	330	1.3	430
Oxygen	320	1.4	450

2.3 Attenuation of Ultrasound

It is well known that sound energy decreases with the distance traveled within the material. In idealized materials, amplitude of sound is only reduced by the spreading of the wave [11]. Natural materials, however, all produce an effect that further weakens the sound [9]. These further weakening results are scattering and absorption. The combined effect of scattering and absorption is called attenuation [1]. The Figure 2 below shows the ultrasound is attenuating as it propagates through its way.

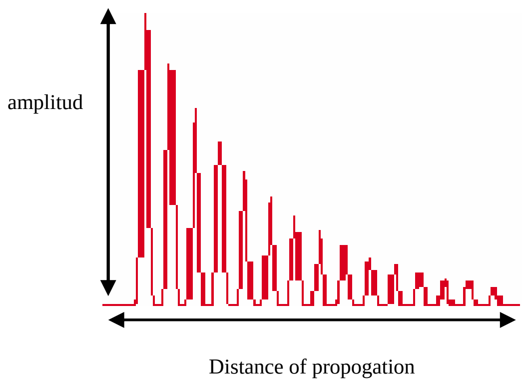


Figure 2. Attenuation of ultrasound.

3. RESEARCH IMPLEMENTATION

The frequency of the ultrasonic sensor that used is 40 kHz. There are altogether eight ultrasonic sensors used and are mounted around the periphery of the pipe. Four of the sensors are transmitters and the other four are the receivers. The measurement is based on the propagation of the ultrasonic wave that is affected by the acoustic impedance of the flow. The water and oil flow with different composition will give the different acoustic impedance. Figure 3 shows the implementation of the research.

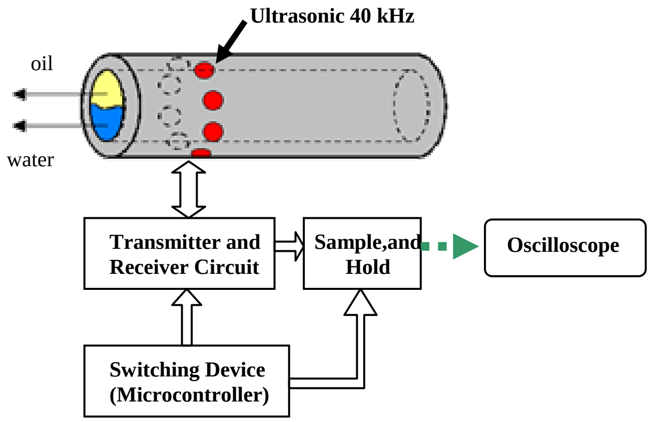


Figure 3. Block diagram showing the ultrasonic tomography

4.1 Ultrasonic Sensor

The ultrasonic sensor that was used in the project is the air ultrasonic ceramic transducers with a frequency of 40 kHz of its frequency. The Figure 4 shows the cross-section view of the ultrasonic sensors for both the transmitter and the receiver:

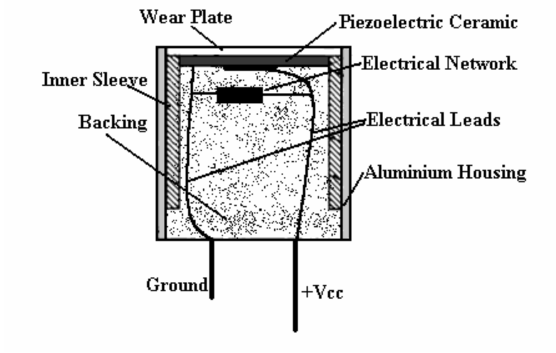


Figure 4. Cross-section view of Ultrasonic Sensor

4.1.1 Beam Angle of Ultrasonic Sensor

Beam angle is an important consideration in ultrasonic sensors selection. The beam angle of the ultrasonic sensor for this research is 30° typical. Therefore, the coverage of the ultrasonic waves can be illustrated by the Figure 5 as follows.

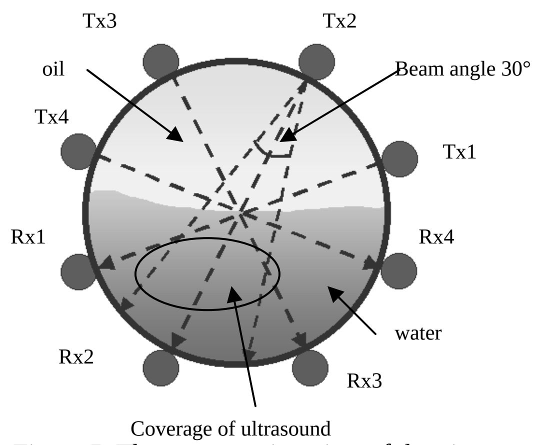


Figure 5. The cross-section view of the pipe.

4.1.2 Fabrication of the Ultrasonic Sensor

The ultrasonic sensors are mounted on the surface of the pipe by using a little of grease. It is implemented non-invasively. The silicone glue is used to fix the small pipe permanently on the pipe. Figure 6 shows the mounting of the ultrasonic sensors on the surface of the pipe

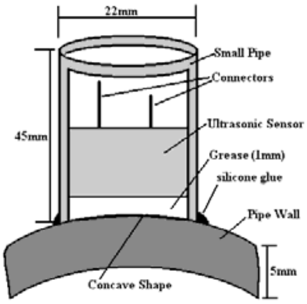


Figure 6. The mounting of the ultrasonic sensors on the surface of the pipe.

4.2 Ultrasonic Transmitter Circuit

4.2.1 Signal Generator

The PIC16F84A (Peripheral Interface Controller) was used as the signal generator in the research. The PIC16F84A was used to generate the pulses to the four transmitter circuits. The frequency for each of the channel is 40 kHz. The signals for each of the channels are shown in Figure 7 below

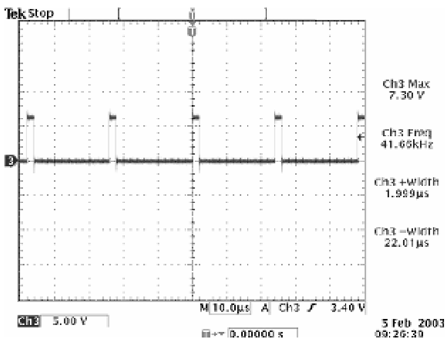


Figure 7. Pulses from the signal generators.

4.2.1 Comparator Circuit

The comparator circuit was used as the driving circuit that produces the required voltages, +15V and 0V to drive the ultrasonic sensors. Signals from the comparator circuit are shown in Figure 8 and Figure 9 when the circuit was connected to the ultrasonic sensor.

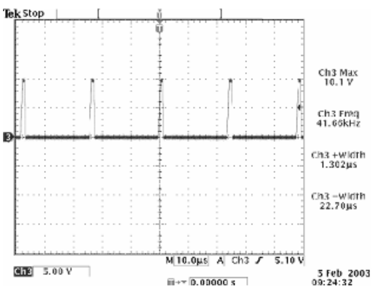


Figure 8. Signals from the comparator circuit.

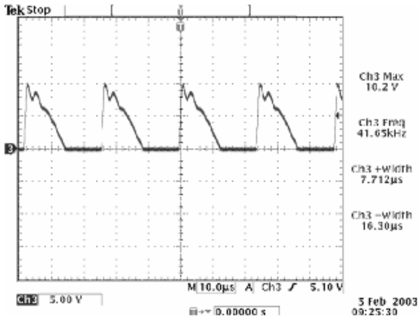


Figure 9. Signals from the comparator circuit.

The signals change its shape due to the ringing effect. The ringing effect is caused by the diaphragm of the ultrasonic sensor which is still vibrating although the pulse signal has stopped. However, it does not bring any effect to the transmitter because the vibration of the diaphragm of the ultrasonic sensor has stopped before the diaphragm of the sensor starts to vibrate again due to another pulse signal.

4.3 Ultrasonic Receiver Circuit

4.3.1 Inverting Amplifier Circuit

For the operation of the inverting amplifier, an amplified but inverted (180^{o} phase shifted) version of the input signal appeared at the output. The gain of the inverting amplifier used is 100dB. The signal from the inverting amplifier circuit is shown in Figure 10.

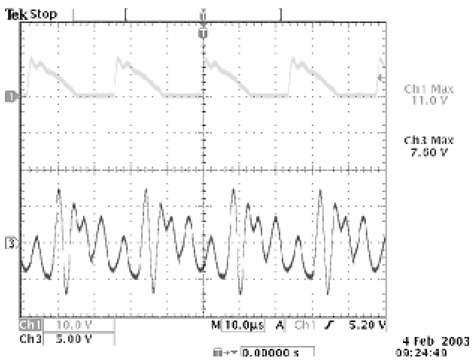


Figure 10. Signals from the inverting amplifier circuit.

4.3.2 Absolute Circuit

The absolute circuit is designed to provide the absolute value (|VALUE|) of the AC signal that received. The output of the absolute circuit will be equal to the input voltage without regard to its polarity or sign [10]. The Figure 11 shows the signals from the absolute circuit.

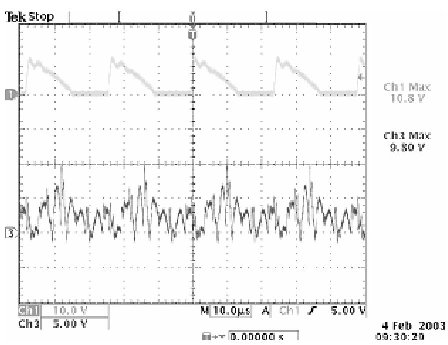


Figure 11. The signals of the absolute circuit.

4.3.3 Sample and Hold Circuit

A sample and hold circuit was used to capture and hold an analog signal in a specific point under control of the microcontroller, PIC16F84A. The signals of the sample and hold circuit are shown in the Figure 12. The high logic is the sampling and the low logic is the holding.

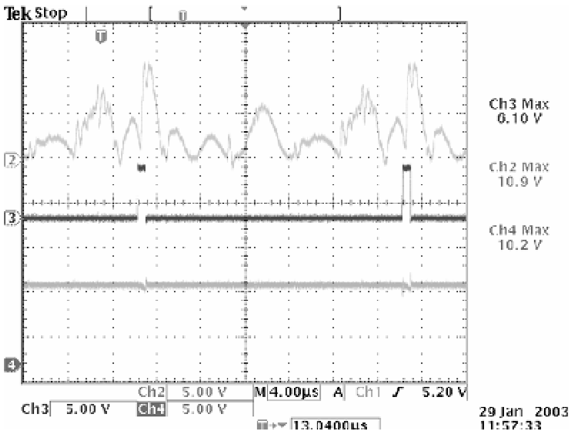


Figure 12. The signals from the sample and hold circuit.

The sampling time that is used in the research is very short, 1.5uS. Therefore, the output from the sample and hold circuit is almost a straight line with certain magnitude. The magnitude of this straight line will change if the composition of the water and oil flow changes. The magnitude of the signal is measured by using the digital oscilloscope.

5. ANALYSIS

5.1 Measurements

The total volume of the flow in the horizontal pipe is measured using a measuring jug that is found to be 8750ml. At first, the pipe will be filled with water only. The output signals from the sample and hold circuits will be measured. By using the same procedure, it is then seven different composition of the water and oil based on the total volume of the flow is measured.

Therefore, there are altogether seven different compositions of water and oil are measured. The assumptions that are made during the measurement are as follows:

(i) The measuring jug was calibrated properly.
(ii) The water and oil never mix up. The oil always floats on the water.
(iii) The internal surface of the pipe is clean and not oily. Therefore, the measurement of the water and oil is not affected.
(iv) The internal surface of the pipe is still wet each time a new volume of water and oil is poured inside the pipe. The composition of the water and oil will be affected. However, this small percentage of volume increasing can be neglected.
(v) The temperature in the laboratory does not have any affect on the volume and composition of the water and oil.

The seven different compositions of the water and oil are measured four times and the measurements that obtained are shown in Table 2.

Table 2. Measurements from the research

Composition		Average (Total/4)
Water (%)	Oil (%)	
100	0	30.21V
80	20	19.70V
60	40	13.42V
50	50	11.31V
40	60	9.75V
20	80	5.56V
0	100	4.53V

From Table 2, it is obvious that the average value of the measurements will decrease when the percentage of the oil increase. This is due to the increase of the oil that has higher acoustic impedance. Table 3 shows the measurements obtained when the pipe is empty.

Table 3. Measurements obtained when the pipe is empty.

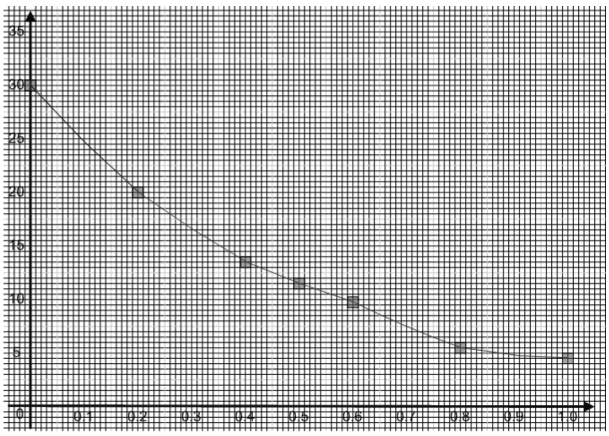
Rx	Data 1 (V)	Data 2 (V)	Data 3 (V)
1	0.6	0.70	0.6
2	0.5	0.65	0.55
3	1.3	1.00	1.26
4	1.6	2.00	1.90
Total	4.00V	4.35V	4.31V

Therefore, it is obvious that when the total value of the measurements is less than 4.5V, it means that the pipe is empty or nothing flows inside the pipe. Then, composition of the water and oil flow cannot be determined.

5.2 Data Analysis

The graph of the average value of the measurement versus the percentage of the oil is drawn and shown in Figure 13. The graph of average value versus percentage of oil does not show a linear relationship. However, it shows that the average value of the measurements is decreasing when the percentage of the oil is increasing.

Average value



Percentage of oil(x100%)

Figure 13. The Graph of Average Value vs Percentage of Oil.

6. DISCUSSION

For getting a better graph to represent the composition of the water and oil, measurements more than four should be made. Certain mathematic method to find an equation that can represent the graph should also be investigated. However, the composition of the water and oil flow can be determined already from the graph based on the total value of the measurements.

It is found that the measurements of the water and oil flow for the same composition vary each time the measurement is made. This may due to some reasons as follows:

(i) The composition of the water and oil is measured using the measuring jug with the smallest scale, 25ml. Therefore, the composition of the water and oil is not measured exactly as it is.

(ii) The pipe is not washed very clean after it is filled with oil. This caused the internal surface of the pipe very oily. When the clean water is filled into the pipe, the water will mix with the oil. The water is not pure anymore.

(iii) The cooking oil that is used in the research has been reused many times for taking the measurement. It is oil mixed with a little bit of water rather than pure cooking oil. This also contributes to the measurement's error.

6 CONCLUSION

Generally, the objectives of this research have been achieved. The transmission mode of the ultrasonic tomography is investigated and implemented in the composition determination of the water and oil flow. The mounting technique using the grease is implemented successfully in the research. It is a non-invasive application. The signal conditioning circuit is also implemented successfully. The output signals vary with the changing of the composition of water and oil. The microcontroller is used efficiently for the timing control.

The data that is obtained in the project has been analyzed and a graph is drawn based on the data. The relationship between the total value and the percentage of the oil is shown from the graph. It is proved that different composition of water and oil shows a different average value of measurements.

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