Abstract—This paper presents the development of an ultrasonic tomography system for multiphase flow imaging. Ultrasonic tomography (UT) modality has a hard-field sensing principle which makes feasible to measure liquid-gas, liquid-liquid and liquid-solid flow composition within a pipe vessel. The sensor configuration for the UT system is discussed along with its signal conditioning circuitry and image reconstruction technique. The feasibility of the system is experimentally carried out on a 100 mm acrylic pipe for a stratified multiphase flow measurement to reconstruct tomographic images.

Keywords—ultrasonic tomography, signal conditioning, image reconstruction, multiphase flow imaging

I. INTRODUCTION

In the production of oil and gas, it is common to have multiphase in the well [1]. Multiphase flow for oil and gas industry has an increasing demand for reliable information on the rate flow, velocities and the volume of the multiphase composition. There is a need for a facility to visualize the characterization of the actual condition inside the well to optimize and sustain the production of oil and gas. The conventional and advance solution requires high maintenance, intrusive, bulky and expansive as it associated with addition visualization device such as a high-speed camera [2][3].

Tomography is a well-established technique used to reconstruct cross-sectional images of a region of interest. This technique is suitable to investigate the internal activity within a pipe vessel thus obtaining measurements from multiple viewpoints. The basic block diagram of a tomography system is depicted in Figure 1.

![Basic block diagram of a tomography system](image-url)

Figure 1. Basic block diagram of a tomography system

Basically, there are two types of tomography system namely the hard-field type such as ultrasonic tomography, x-ray tomography whereby its principle is based on wave transmission, reflection and deflection. The other type of tomography system called as soft-field type or also known as electrical tomography such as electrical capacitance...
tomography (ECT), electrical resistance tomography (ERT) and electrical impedance tomography (EIT). Unlike the hard-field type, electrical tomography relies upon the distribution of the electrical field within the region of interest.

The non-intrusiveness of tomography technique make it superior to other techniques such as mechanical and vortex flow meter [4][5]. Research in magnetic resonance-based technique offers imaging and measurement of the multiphase flow. However, the working principle of this technique produces a hazardous working environment [6][7][8]. Capacitance measurement tomography offers cheap and simple fabrication [9][10]. However, this technique suffers from the soft-field effect and has a low sensitivity to spatial distribution [11].

II. HARDWARE CONFIGURATION

The dual-modality tomography (DMT) hardware system consist of an integration of 16 units of ultrasonic transducers as depicted in Figure 2.

A. Sensor Configuration

The total of 16 sensors are mounted on a cylindrical pipeline. In order to attach the sensor evenly on the curved circumference, a layer of coupling gel is required to act as a wave propagation medium and to fill up the air gap exist between the ultrasonic sensor and the pipe surface.

B. Excitation setup

The ultrasonic transmitter emits acoustic signal by applying 40 kHz short pulsed signal with a 10 ms delay between each transmission across it rather than using continuous oscillating signals as depicted in Figure 4. This is to avoid overlapping signals mixed up together thus causes difficulties in distinguishing the required signal information accurately for further signal processing purpose.

Each sensor alternately transmits acoustic signal while the remaining 15 sensors will receive this signals simultaneously. To carry out these process, a signal conditioning circuit consisting a receiving circuit with an analogue circuit (AC) amplifier, signal filtering circuit, an analogue to digital (ADC) unit using full wave rectifier is designed. Figure 5 shows a UT receiving circuit diagram with two stage amplifier using a dual high speed operational amplifier LM6172M. The first stage amplifies weak signal with gain $A_v = -100$ while second stage amplifies with gain $A_v = -10$ after bandpass filtering process take place. These amplified signal response is shown in Figure 6.

![Figure 3: Sensor mounting on a curved pipe surface](image)

![Figure 4: 49 kHz ultrasound pulse generation](image)

![Figure 5: Ultrasonic receiving circuit diagram](image)
The AC response of the receiving signals needs to be converted into DC signal for subsequent signal process. The amplified and filtered signals of UT is converted into unipolar signal and then into DC level by using a precision full wave rectifier circuit. Full wave rectifier circuit produces an output voltage which is purely DC thus producing a smoother output waveform. The signal waveform is reshaped into unipolar DC level. Both polarities of the input signal produce the same polarity as the output signal, which is, by definition, an absolute value function. The rectified signal waveform of UT (as shown in Figure 6) is send to a computer via a for post-processing.

III. IMAGE RECONSTRUCTION

The incoming acoustic signals of each ultrasonic sensor are obtained after the process of signal conditioning. A total of 240 signals are required for a 16 channel sensor system to complete 1 full scan. To reconstruct images out of these data, the forward problem will determine the theoretical output of each sensor when the sensing region is considered as two dimensional. This can be solved by using the analytical solution of sensitivity maps which produces sensitivity matrices as in Figure 7.

A. Linear back projection

The final image result is reconstructed by using Linear Back Projection (LBP) technique. LBP method is the simplest yet fastest image reconstruction technique to generate cross-sectional images representing the internal activity of a pipeline. Further explanation on LBP is discussed in [12][13][14][15] The concentration profile is generated by combining the projection data from each sensor with its computed sensitivity maps. This method is computationally straightforward to implement besides low computation cost and is popular method for image reconstruction. The measurements obtained at each projected data are the attenuated sensor values due to object space in the image plane. These sensor values are then back projected by multiply
with the corresponding normalized sensitivity maps according to the equation (1).

\[ V_{LBP}(x, y) = \sum_{Tx=1}^{16} \sum_{Rx=1}^{16} S_{Tx,Rx} \times M_{Tx,Rx}(x, y) \]  

(1)

where \( V_{LBP}(x, y) \) is the voltage distribution obtained using LBP, \( S_{Tx,Rx} \) is the sensor voltage of transmitter (Tx) and receiver (Rx) and \( M_{Tx,Rx} \) is the normalized sensitivity maps.

The obtained voltage distribution \( V_{LBP}(x, y) \) will represent the final output image of a particular flow condition within the pipeline.

IV. RESULT AND DISCUSSION

To test the UT system, five test profiles were configured to carry out this experiment. These test profiles are obtained via visual inspection of a static flow from the acrylic pipe (see figure 2). Following Figure 8 shows the reconstructed test profile using linear back projection (LBP).

![Reconstructed image results for stratified multi-phase flow](image)

Figure 8. Reconstructed image results for stratified multi-phase flow

Over the five test profiles for UT in Figure 8, the linear back projection (LBP) technique has successfully reconstructed images from the sensor value obtained from the UT hardware system. Although the cross-sectional image is obtained, but these images suffer from blurry artefacts due to the hard-field characteristic of ultrasonic wave propagation. The image shows better measurement (higher density) towards the centre of the sensing region whilst lower density towards the corner. However, the LBP technique is able to reconstruct the flow regime of a multi-phase flow.

V. CONCLUSION

The ultrasonic tomography hardware system is developed to measure multi-phase flow consisting liquid-liquid, liquid-gas or liquid-solid composition. The system will be able to detect the two types of composition due to the difference of material density. The signal conditioning circuitry has managed to obtain the incoming acoustic signal from each sensor and feed it to an image reconstruction technique; Linear back projection (LBP). The image reconstruction using LBP technique has successfully produce the cross-sectional image of a multi-phase flow regime.

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