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ULTRASONIC TOMOGRAPHY: THE TRANSDUCER CHARACTERISTICS AND HARDWARE CONTROL

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7.1 INTRODUCTION

Ultrasonic transducer plays an important role in ultrasonic tomography system besides its associated electronic hardware. This is important for acquiring the data needed to produce a meaningful image. This is fundamental to the success or failure of an acoustic imaging system. Therefore, given the object to be imaged and the specifications to be achieved, the design of the front-end of an acoustic imaging system should be regarded as a first priority [1].

7.2 TRANSDUCER SENSITIVITY

Ultrasonic transducer is a device capable of converting electrical energy into high frequency sound waves, and also converting sound waves back into electrical energy. Ultrasonic transducer contains piezoelectric crystal materials that have the ability to transform mechanical energy into electrical energy, and vice versa. In reality, when a crystal element is pulsed with a voltage profile, a wave starts travelling from each face of the crystal element. The vibrational mode of the crystal can therefore only be considered from a transient wave propagation viewpoint.

The penetrating power and sensitivity of an ultrasonic wave depends on the resulting wavelength of excitation inside the material. Greater wavelengths or lower frequencies generally penetrate much further in to a material [2]. Higher frequency ultrasonic excitations with smaller wavelengths generally decay more rapidly inside a material, but sensitivity capability is improved. The relationship of a wavelength and a frequency of an ultrasonic signal are expressed in equation below:

$$v = f\lambda \qquad (7.1)$$

where v = speed of sound (m/s), f = ultrasonic frequency (Hz) and λ = the wavelength (m).

The sensitivity of a 333 kHz ultrasonic transducer in water media can be obtained directly from Equation 7.1. Knowing that the speed of sound in water is 1480 m/s, therefore the wavelength obtained is 4.44 mm. By taking the sensitivity of the transducer at one-half the wavelength, thus the smallest detectable gas cavity in this case is approximately 2.22 mm. Depends on application where the detectable subject might be smaller, thus using higher frequency transducer might solve the problem i.e. 2 MHz transducer capable of detecting 0.37 mm gas hold-ups.

An experimental work has been conducted to show this relationship. A number of test rod samples have been tested on two different ultrasonic frequencies. The experimental setup is shown in Figure 7.1. In this experiment, the test rods were inserted in a column filled with water and the response of both ultrasonic signals were observed on a digital oscilloscope. The attenuation of the receiving ultrasonic signal can be observed if the test rod diameter is greater than one-half the wavelength. Figure 7.2 shows the results of the experiment.

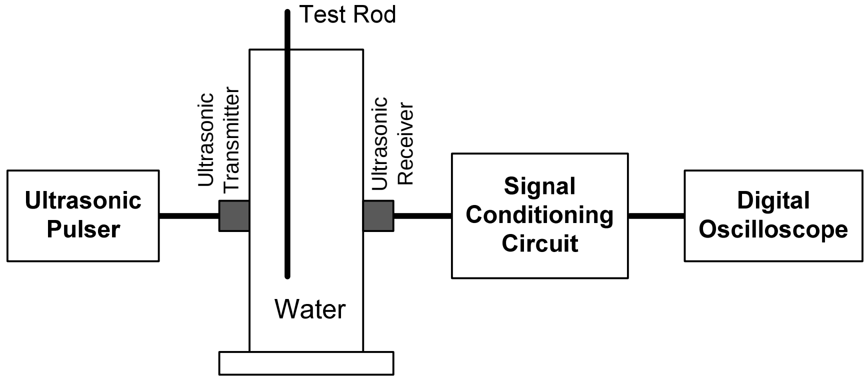


Figure 7.1. Experimental setup to observe the transducer sensitivity

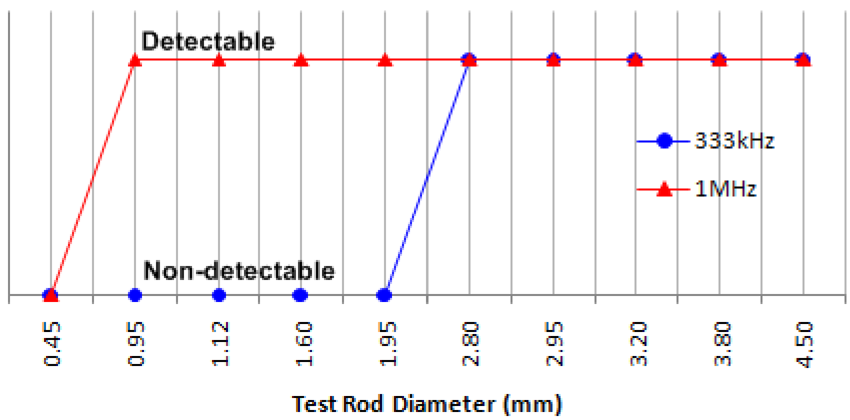
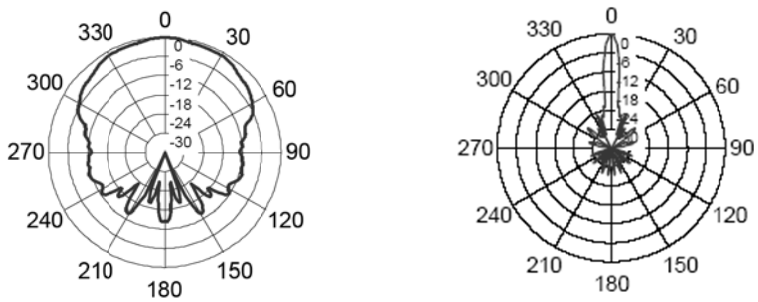


Figure 7.2. Sensitivity for both 333 kHz and 1 MHz transducer

7.3 TRANSDUCER BEAM SPREAD

Transducer elements employed in ultrasonic imaging arrays may be designed to produce either a narrow focused beam or a wide angle beam. The wide angle beam is also known as 'fan-shaped beam'. The 'fan-shaped beam' ensures maximum number of views of transducers located around the process column. The examples of polar diagram for wide angle and narrow focused beam of ultrasonic transducer are shown in Figure 7.3.



a) Wide angle beam b) Narrow focused beam

Figure 7.3. Polar diagram for wide angle and narrow focused ultrasonic beam

There are two features usually present in industrial multiphase flows. One is that the flow can move very rapidly compared to any other objects imaged in the existing acoustic imaging systems, for example up to more than ten meters per second. The other is that the flow regimes are of extreme complexity. Particularly when gaseous components are contained in the flow, ultrasound could become inadequate in some situations. These two features in industrial flows bring problems to flow imaging because of two physical properties of ultrasound.

For medical diagnostic imaging application, the imaged objects are slow moving or quasi-static. Therefore, the valid measurement can be up to thousands of data for one frame of an image compared to flow imaging in industries where the objects might have flown away before the complete measurement round is finished. Therefore the speed of ultrasound limits the system performance.

In liquid/gas two phase flows, ultrasonic waves could not penetrate a gas bubbles or regime in the process column. Because of the enormous difference in impedances between gases and most commonly liquid, the liquid/gas boundary will reflect most of the acoustic energy propagating from the liquid to the gas phase [3]. Anything inside the gas cavity is virtually unreachable and the back wall of a bubble or objects behind the bubble cannot be properly detected. To cater this problem, the flow must be viewed from as many angles as possible. A number of transducers can be arranged around a cross-section of the pipe. This will define an image plane. By having a 'fan-shaped beam' transducer, the measurement resolution could tremendously improve.

7.4 HARDWARE REQURIEMENT

To construct the best possible image from the limited number of interrogations in each measurement round, it is essential to obtain as much information as possible from each interrogation. A transducer having a fan-shaped beam pattern will cover a wide angle of the flow media in the image plane. This is a method which gains more information in an individual interrogation. If more transducers are provided, more measurements can be obtained and a better quality of image can be expected.

The generic electronic measurement system for an ultrasonic tomography system is shown in Figure 7.4. The usage of microcontroller simplifies the digital circuits. Besides, the synchronization of the transmitting and receiving ultrasonic signals is ensured. The microcontroller can be used to control and generates ultrasonic burst tones as shown in Figure 7.5.

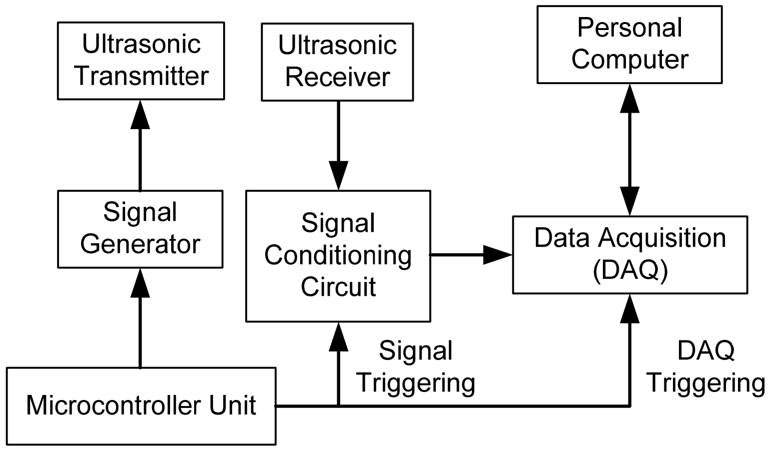


Figure 7.4. The ultrasonic system block diagram

The burst tones consist of dual frequencies namely the minor and major frequency. The minor frequency is the 333 kHz which is the two cycles of ultrasonic pulses with duty cycle of 50% at each pulse. The major frequency is the 150 Hz signal for the reverberation effect delays of receiver before the next transmitter excitation. The reverberation effect delays are needed to avoid overlapping echoes at the receiving transducer due to two separate ultrasound excitation.

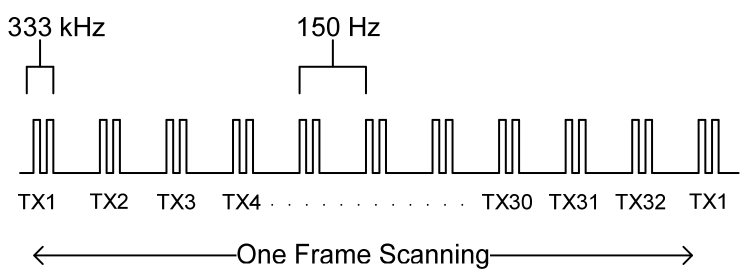


Figure 7.5. The burst tones

The signal conditioning circuit will process the receiving signals and prepare the signal information to be collected by the data acquisition system. A personal computer will be used to display the tomogram requires a suitable image reconstruction algorithm such as the Linear Back Projection algorithm. The image reconstructed will be meaningful to the scientists and engineers for analyzing and monitoring the industrial flows.

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REFERENCES

[1] Mohd Hafiz Fazalul Rahiman, Ruzairi Abdul Rahim, Mohd Hezri Fazalul Rahiman and Mazidah Tajjudin. “Ultrasonic Transmission-Mode Tomography Imaging for Liquid/Gas Two-Phase Flow”. *IEEE Sensors Journal*, vol. 6, no. 6, pp. 1706-1715, 2006.

[2] Kannath, A. and Dewhurst, R. J. “Real-Time Measurement of Acoustic Field Displacements Using Ultrasonic Interferometry”. *Measurement Science Technology*, vol. 15, pp. 59–66, 2004.

[3] M.H. Fazalul Rahiman, R. Abdul Rahim, Z. Zakaria. "Design and Modelling of Ultrasonic Tomography for Two Component High Acoustic Impedance Mixture". Sensors & Actuators: A. Physical, vol. 147, issue 2, pp. 409-414, 2008.