Tomography Systems and Sensor Applications
Velocity Measurement of Gas Bubbles Flow in Vertical Water Column Using Ultrasonic Sensor

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Abstract

The purpose of this paper is to present an implementation of measurement system using ultrasonic sensor to detect and measure the velocity flow of gas bubbles in vertical water column. The selection of the sensors is important and must be suitable to the application design. Consideration on the natural limitation of ultrasonic wave is also noted as the higher the frequency of the ultrasonic sensor, the better the sensitivity but lower penetration depth. 2-pairs of ultrasonic sensors are installed non-invasively at the periphery of an acrylic pipe. The glue is used as the coupling material to mount these ultrasonic sensors. The paper finds that information about the gas bubbles in liquid flow that obtained from the sensors' measurements. At the end of this project, the data that obtained able to used in working computed controlling, monitoring in related industrial process.

Keywords: Velocity, Ultrasonic Sensor

1. Introduction

Process monitoring plays an important role in most area such as in industries and research field. Widespread need for the monitoring of the internal activities of process plants arises to further improve the design and operation of the process plant. Thus, process measurement has the requirements of providing the solutions on the need of such monitoring system with the advantage of providing quantitative data of the internal behaviour without disrupting the process plant [1].

Ultrasonic sensor has the advantage of providing a monitoring system able to reconstruct the distribution of a gas/liquid two-phase flow over the cross-section of a pipe while being non-invasive and possibly non-intrusive to the corresponding activities inside the column [2]. The system can be used for the measurement of two-component flow such as liquid or gas flow through a pipeline or any process vessel which is increasingly of importance in many industrial processes (e.g. oil exploration, flow behaviour monitoring, turbulence control, chemical process monitoring, chemical mixing etc). Wide range of applications can benefit by the use of Ultrasonic sensor measurement system.

Detection of bubble is also a requirement in much industrial application which includes filling operations in the paint, detergents, food, cosmetics and pharmaceutical industries where bubble may degrade the product [3]. Optimizing the harvesting process and transportation in petrochemical industry also requires the detection of bubble. Gas which had dissolved into the crude in the high pressure at the well base exsolves as the crude is brought up to surface pressure. Bubble detection in the bore may warn of high-pressure gas pockets. In hydroelectric stations, bubble detection gives warning of cavitations [4].

Ultrasonic bubble detection has other industrial applications, including fluid processing, pressure measurement, and pressure vessel monitoring. Medical applications include studies of decompression sickness, and contrast echocardiography. Bubble in vivo can be detected actively and passively.

By A bubble in liquid will in general contain a mixture of permanent gas and vapour [5] and will be approximately stable over timescales where dissolution and buoyancy may be neglected if the partial pressure of the gas component roughly counterbalances the constricting pressure due to surface tension and the pressure in the surrounding liquid (which may consist of acoustic or hydrodynamic pressure perturbations superimposed upon a hydrostatic field). An acoustic field can drive it into nonlinear pulsation (termed stable cavitation's), which at small amplitudes of freedom linear oscillator. Shape and surface oscillations may also occur, and may be associated with micro streaming flows about the bubble [4].

This clearly shows that there is a widespread need for the direct analysis of the internal characteristics of the process plant in order to improve the design and operation of equipment in various industries. The measurement of two-component flow such as liquid and gas flow through a pipe is increasingly important in many applications and it is proven that the operation efficiency of such process is closely related to accurate measurement and control of hydrodynamic parameters such as flow regime and flow.

2. Methodology

Designing the front end of an ultrasonic measurement system is among the most important parts; one can say that they are the eyes and ears of the system. This includes mounting the 2-pairs of ultrasonic transmitters and receivers which is considered as the sensing area (Figure 1.1) for the ultrasonic measurement system. Associated electronic measurement circuits are then designed to process the output from the sensing area.

This is important for acquiring the precise data. This is fundamental to the success or failure of a measuring system. Therefore, given the object to be measured and the specifications to be achieved, the design of the front end of an acoustic system should be regarded as a first priority [6].

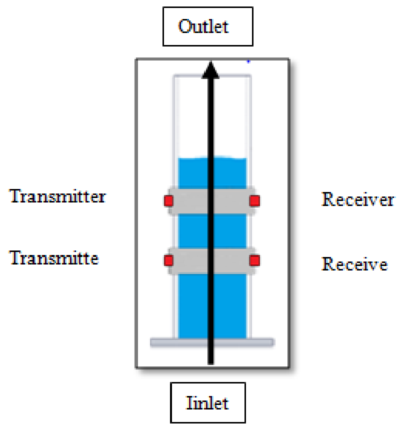

Figure 1.1 Sensing area consists of 2-pairs of ultrasonic transducers.

Generally, the design of an ultrasonic measurement system is divided into 3 small parts: 1) sensing area, 2) electronics, 3) and display module. As have been introduced earlier, the sensing area is made up of 2-pair of ultrasonic transmitters and receivers. The other electronic and signal processing circuits are as shown in the above block diagram (Figure 1.2).

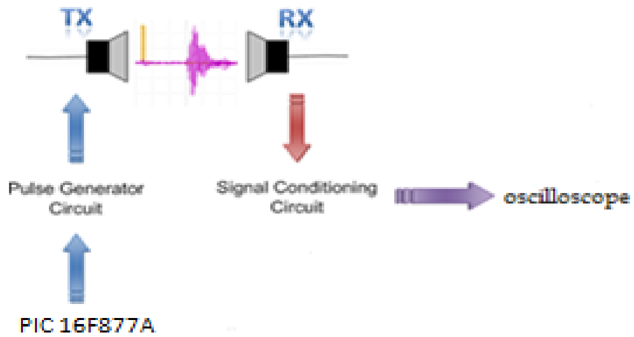

Figure 1.2 Electronics circuitry

2.1 Pulse Generator Circuit

The Pulse Generator Circuit (Figure 2.1) is a simple ultrasonic transmitter circuit that uses Operation Amplifier (op-amp) as a comparator. The op-amp used is TLE2141 from Texas Instruments (TI).

The TLE2141 op-amp that is used as a comparator operates without negative feedback. When the non-inverting input (V+) is at a higher voltage than the inverting input (V-), the high gain of the op-amp causes it to output the most positive voltage it can. When the non-inverting input (V+) drops below the inverting input (V-), the op-amp outputs the most negative voltage it can. Since the output voltage is limited by the supply voltage, for an op-amp that used a single supply (powered by 0 to +15V) this action can be written:

$$
\begin{aligned}
Vout \quad &= Vsupply+ \;,(V+ > V-) \\
&= Vsupply- \;,(V+ < V-)
\end{aligned} \tag{1}
$$

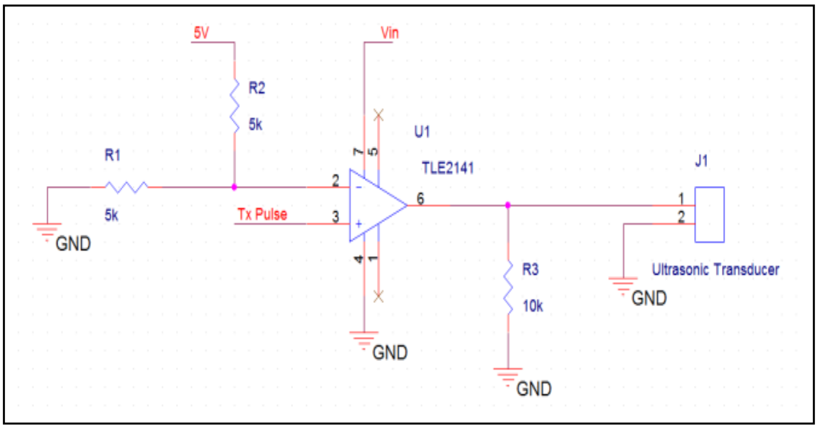

Figure 2.1 Pulse Generator Circuit schematic

2.2 Signal Conditioning Circuit

Appropriate low-noise signal conditioning circuit is used for the hardware development. The signal conditioning circuit purpose is to filter DC signals and amplify the received ultrasound energy. The initial value from the ultrasonic receivers are fairly small which makes it hard to differentiate the voltage readings for different conditions, thus for the system to read its signal, the signal conditioning circuit are designed to amplify the receiving signals.

As shown in Figure 2.2 below, two Operational Amplifiers (Op-Amps) are used to construct a 2-stage inverting amplifiers that will significantly increase the magnitude of the input signals from the ultrasonic transducer. Both stages have a gain of -150 as shown in the calculation below:

$$\mathrm{A(1st\ stage)} = -\frac{R3}{R2} = -\frac{15000}{100} = -150$$

$$\mathrm{A(2nd\ stage)} = -\frac{R5}{R4} = -\frac{15000}{100} = -150$$

Since multiple amplifiers are staged, their respective gains form an overall gain equal to the multiplication of the individual gains.

$$\begin{aligned} Atotal &= A1st\ stage \times A2nd\ stage \qquad (2) \\ &= -150 \times -150 \\ &= 22{,}500 \end{aligned}$$

Therefore total gain of the chain of cascaded amplifiers used in this research to increase the input signal of the receiving ultrasonic sensor is 22,500.

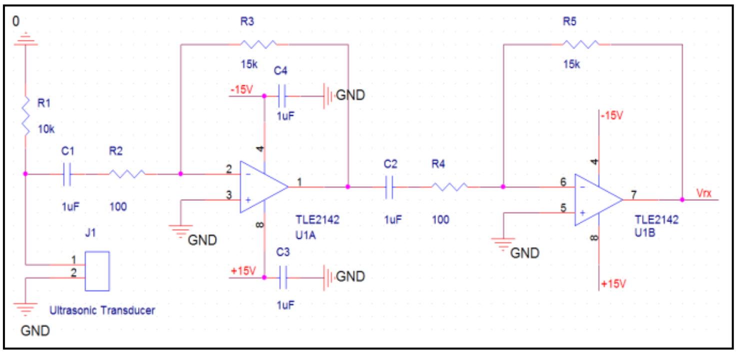

Figure 2.2 Signal Conditioning Circuit

3. Conclusion

The non-invasive ultrasonic measurement for gas bubbles flow have been implement and investigated. The experimental results show that this system could be used to identify and detect small bubble in the investigated column. Ultrasonic sensors with much higher frequencies can be used if smaller detection of gas bubble is needed. The limitation of ultrasound wave presents a trade-off challenge in developing an ultrasonic measurement system. The speed of ultrasound sets the upper limit of flow rates to which ultrasound techniques can be applied for flow measurement. To cater this natural disadvantage, it is vital that the flow activities inside the investigated column must be viewed from as many angles as possible, which can be solved by using fan-shaped beam projection. The essence in utilizing the fan-shaped beam is that more information can be obtained from each interrogation.

A sensor with such fan-shaped beam pattern will a cover a wide angle of the flow activities inside the column from a single excited transmitter. Although it is apparent that a wide beam angle of ultrasound wave is important so that the system can gather information at a greater extent, the ultrasonic measurement system that employ wide-beam sensor will suffer in terms of attenuation of the ultrasonic beam with distance. Wide beam angles reduce the sensing range of the sensor by spreading acoustic energy over a greater volume and hence less acoustic energy is transmitted to the respective receivers.

When compared to wide beams, a transducer with narrow beam angles does not have the advantage of gaining more information in an individual interrogation but the ultrasonic measurement system that utilizes these sensors transmit more concentrated beam that travels over more distance with the added advantage of higher sensitivity.

Thus it is crucial to balance the trade-offs in developing an ultrasonic measurement system by considering the optimum frequency the system should use for the size of the column being investigated.

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