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Ultrasonic Simulation Research of Solid Particle Radial Position Distribution in Gas-solid Two Phase Flow

Yueming WANG[1], Guodong YAO[1,2], Hua JIA[1], Yaoyao ZHANG[1], Meng LIU[1], Pengcheng GE[1]
[1]School of information engineering, Inner Mongolia University of Science and Technology
Baotou, Inner Mongolia, China

Guodong YAO[1,2]
[2]Tech. PMT, CNCEC Sixth Construction Company, Xiang yang, Hu Bei, China

***Abstract*—In industrial production, the gas-solid two-phase flow involves a wide range. The parameters of the two-phase flow measurement become one of the hot research works. By COMSOL software, a radial simulation model is set up to study particle distribution in radial section and their sensitivity. And also, the signals received by the ultrasonic sensor in different frequency and locations are analyzed. Thus, it provides a reference for the ultrasonic method to measure the sensitive field of the radial section of gas solid two phase flow, and provides the internal mechanism analysis for the ultrasonic measurement of gas-solid two-phase flow.**

***Keywords*—Gas solid two phase flow; Ultrasonic sensor; Particle distribution; Signal; Simulation**

I. INTRODUCTION

The gas-solid two-phase flow application is very popular in the fields of electricity, chemistry, metallurgy, food processing, pharmaceutical and other industrial production process, through the online measurement of the velocity, concentration, particle size and other parameters, can achieve the optimal control, improve production efficiency, reduce energy consumption and so on [1,2] . Ultrasound is a mechanical wave propagation speed, its influence by the media is relatively large, ultrasonic technology can realize non-contact measurement, spatial distribution and can simultaneously measure the instantaneous velocity, in recent years the application in fluid measurement has been developed a lot. [3] At abroad, it is used to test gas fluid and some ultrasonic measurement devices are mature in the Netherlands, Germany, the United States, South Korea and so on. In China, ultrasonic liquid meters are more mature than gas ones, and little research is done in gas ones except in some universities and institutions [4-6], Mingxu Su, Xiaoshu Cai et al have done some research about ultrasonic attenuation and velocity of ultrafine particles suspension liquid [7,8] , Zheng Dandan et al have done some research about ultrasonic flow measurement of the transducer on the flow field disturbance mechanism and different channel layout [9,10]. Dong Feng et al. Proposed the electrode and ultrasonic probe in the same section of the pipe with the impedance / ultrasonic dual-mode tomography imaging configuration. The numerical simulation method was used to investigate the distribution of the electrical sensitive field and the ultrasonic sensitive field in the pipeline [11].

The solid-phase particles of gas-solid two-phase flow are randomly distributed in the measurement pipeline. The different position distributions have different effects on the ultrasonic measuring sensor. In this paper, with COMSOL software, a simulation model is built to measure potential distribution and current density as well as sensitivity in the gas-solid two phase flow. And the distribution of the sensitive field inside the pipeline of gas-solid two-phase flow is studied. The simulation result supports the theory of measuring gas-solid two-phase flow in the ultrasonic method.

II. ULTRASONIC TESTING SIMULATION MODEL

In the actual fluid measurement, the gas-solid two-phase solid phase material is randomly dispersed or distributed in the fluid. In order to study the effect of the solid phase particles on the ultrasonic receiving signal in the fluid, the solid in the fluid The particles are distributed in different radial cross-section positions in the fluid, and the different positions of the solid-phase particles of the gas-solid two-phase flow are studied. The influence of the ultrasonic receiving signal at different emission frequencies is analyzed, that is, the sensitivity of the ultrasonic wave in the measurement pipeline Field distribution.

A. Introduction of simulation modeling

Based on ultrasonic measurement of solid phase particles in pipe, a simulation model of gas-solid two phase flow is shown in Figure 1. In Figure 1(a), the pipe radius is set to R(R=150mm), and the section diameter of ultrasonic sensors of emission and reception is set to 10mm. Usually, sensors are composited by flexible compound piezoelectric materials T and H, with T of the emitting terminal, H of the receiving terminal, and their thickness of 4.5mm. The solid phase particles in pipe are set to the diameter of d1=2mm. T and H are located on Y axis, and X axis and Y axis are composited into a rectangular coordinate system. The gap length is 30mm between the centers of particles which are distributed in linear array, shown

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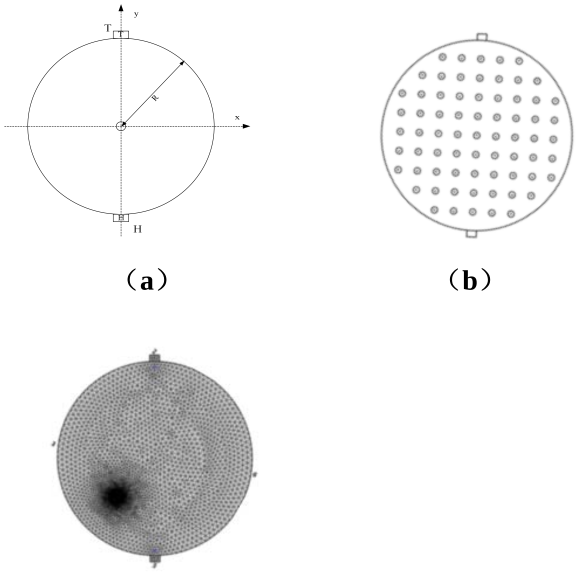
in Figure 1(b). In Figure 1(c), with ultrasonic frequency of 20 kHz and the mesh generation, a simulated mesh dissection model is achieved in the form of triangular mesh. In the simulation experiment, solid phase particles are distributed accordingly (decreasing or increasing particles) to simulate various segregations of gas-solid two phase flow in pipe practically.



(a) (b) (c)

Fig.1 Simulation model

B. The coupling equation of electricity - structure - acoustic system

In the simulation experiment, the sound propagation equation is constructed by the momentum conservation equation and energy conservation equation of the Navier-Stokes equation. Supposing particle sizes are kept constant and lossless, the pipe is adiabatic, viscous effects are neglected, linear isentropic state equations are used, and sound field is depicted by a variable of sound pressure, thus Equation (1) is obtained by solving the wave equation.

$$\frac{1}{\rho c^2}\frac{\partial^2 p}{\partial t^2}+\nabla\cdot(-\frac{1}{\rho}(\nabla pt-q))=Q \quad (1)$$

where ρ stands for the density of material, t represents time, p is the sound pressure, and ∇ is Laplace operator. Q and Q are acoustic dipole source and single pole source respectively, and signals can be converted into a series of harmonic components by Fourier transform. A frequency can be solved once in frequency domain by wave equation. General harmonic component is as Equation (2)：

$$p(x,t)=p(x)\sin(\omega t) \quad (2)$$

where harmonic component peak is p(x), more generally it is Equation (3):

$$p(x,t)=p(x) \quad (3)$$

Physical value of actual sound pressure is the real part in Equation (3). With sound pressure supposed above, transient wave equation shapes in Helmholtz Equation (4):

$$\nabla\cdot(-\frac{1}{\rho}(\nabla pt-q))-\frac{w}{\rho c^2}p=Q \quad (4)$$

In the model, flow media is distributed evenly, and source terms of q and Q equal zero, thus Helmholtz Equation (4) results in a simple solution of plane wave as Equation (5)：

$$p=p_0e^{i(\omega t-k\cdot x)} \quad (5)$$

Where p stands for amplitude and wave goes with the angular frequency of wω and K=|k| in the direction of vector.

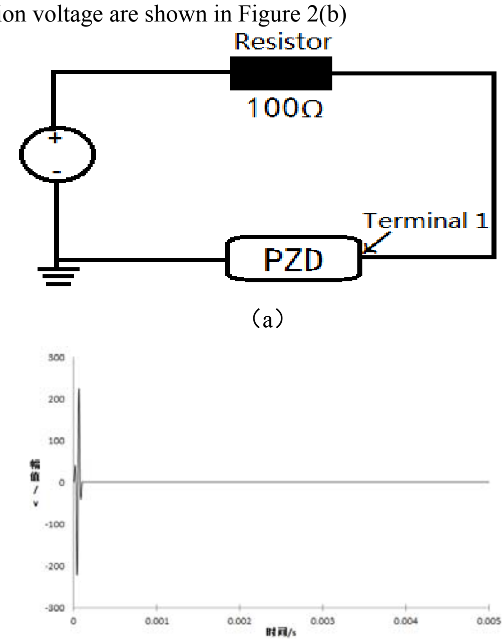
Structural mechanics equation is expressed as Equation (6):

$$\rho\frac{\partial^2 u}{\partial t^2}=\nabla\cdot s+F_V \quad (6)$$

Where ρ stands for piezoelectric material density, u is displacement, Fv is body force, and s is stress. Maxwell's equation of the Electric on piezoelectric material is expressed as Equation (7):

$$\nabla\cdot D=\rho_V \quad (7)$$

In the simulation experiment, the compound piezoelectric material T loaded with an instantaneous sine excitation voltage of 223.72 V is shown in Figure 2(a), and the time domain signals of excitation voltage are shown in Figure 2(b)



(a)

(b)

Fig 2 Equivalent circuit diagram and simulated diagram of excitation voltage signals

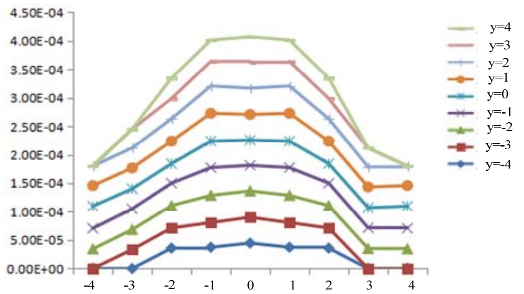
III. THE SIMULATION PROCESS AND ANALYSIS

A. *Simulation and data analysis process*

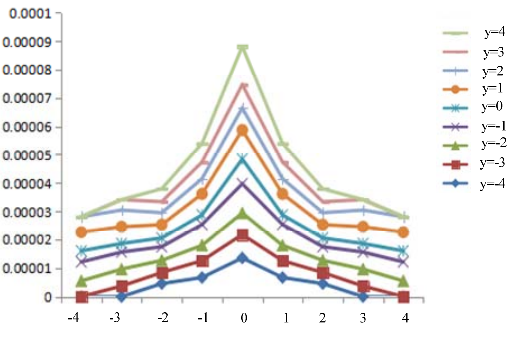
In the simulation experiment of gas-solid two phase flow, particles set with the diameter of 2mm and the particle gap of 30mm are lined in the pipe, and the lines are increased one by one The distribution of particle locations within the pipeline is shown in Figure1(c). In the simulation experiment, a solid phase particle was found in each simulation experiment. The remaining space of the pipeline was air, and the position of the solid particle was different in the experiment. With frequency of 20kHz,30kHz,100kHz , changing the position distribution of the solid particles, and then simulating each position, and recording the data at the receiving end in the simulation experiment. The maximum and minimum values of the data received at the receiving end are obtained according to the distribution of the particles in the pipe cross section, value and average. The distribution of solid particles in the pipeline is shown in Figure 1 (c).

In the simulation experiment, different sound pressure data are obtained with different particle locations, under the different frequencies of 20kHz,30kHz,100kHz separately. The signal data extracted at the ultrasonic receiver is analyzed.

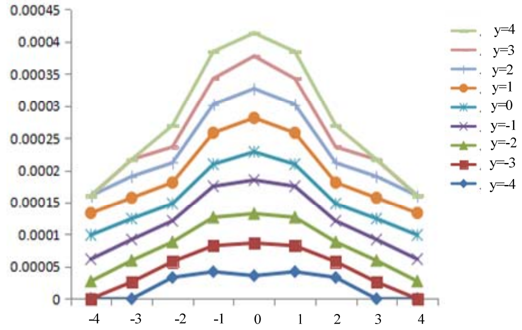
The simulation data show that when the solid phase particles in the fluid are in different positions, the sensitive field of the measurement area inside the radial pipeline changes with the frequency. In order to analyze the influence of the solid particles in the pipeline, the simulation data Preservation and processing, Figure 3 is voltage distributio for the existence of solid material in the fluid and solid phase material with a certain law distributed in the radial section of the pipeline.



(a)



(b)



(c)

Fig.3 the distribution line of the receiving signal of different positions ofradial particles in different transmitting frequencies

Figure 3 shows the distribution of ultrasonic signal in different positions of the gas-solid two-phase flow in the pipeline. In the figure, the horizontal axis represents the different coordinate positions of the solid particles on the x-axis, and the figure shows the solid particles in the y-axis on the different coordinate position, the vertical axis for the ultrasonic signal received signal value. Sub-graph (a) shows the ultrasonic acquisition voltage distribution when the ultrasonic generator frequency of 20 kHz and solid particles at different distribution positions. Sub-graph (b) shows the ultrasonic acquisition voltage distribution when the ultrasonic generator frequency of 30 kHz and solid particles at different distribution position. Sub-graph (c) shows the ultrasonic acquisition voltage distribution when the ultrasonic generator frequency of 100 kHz and solid-phase particles at different locations. It is seen from the figure: the greater the frequency of ultrasonic emissions, the greater the effect of received signal by the gas-solid two-phase solid particles in pipeline on y-axis (Ultrasonic transmitter and receiver on the straight line segment in Figure1), and the greater the frequency. the closer the solid-phase particle distribution is to the y-axis, the closer the effect of received signal is to the y-axis. The closer the solid-phase particle distribution is to the transmitter, the greater the effect of the received signal on the ultrasonic wave, and the effect is spread along both sides of the y-axis

IV. CONCLUSION

In the paper, by COMSOL software, a radial simulation model of ultrasonic transmission in the gas-solid two-phase flow in pipe is set up. From the simulation, the pressure sensitive field of the pipeline is obtained, which can provide the guidance and technical scheme for the design and realization of the ultrasonic sensor in the pneumatic conveying pipeline.

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