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Study on Velocity Profile Measurement of Saturated Jet Flow by Air-coupled Ultrasound

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Abstract

An air-coupled ultrasonic sensor and velocity profiler are developed to measure the steam flow rate. The developed ultrasonic sensor can be adopted to measure the droplets since it has a round surface that can focus the ultrasonic beam with narrow width and high-intensity. Meanwhile the sensor has a matching layer which enables to reduce the acoustic reflection between the sensor and the air. A signal processing for eliminating the side lobe echo noise is installed in the air-coupled ultrasonic velocity profiler so that the steam velocity can be measured, successfully. The flow structure of steam jet is observed that the velocity boundary layer development and the main jet steam increase with the steam flow velocity. Therefore, it is revealed that the steam flow velocity could be measured by air-coupled ultrasound.

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Keywords: Ultrasonic Velocity Profiler; Steam jet; Flow measurement; Air-coupled ultrasound

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Nomenclature

c	Sound velocity [m/s]
V	Flow velocity [m/s]
f_0	Basic frequency of ultrasound [Hz]
f_{prf}	Pulse repetition frequency [Hz]
A	Amplitude of detected signal [-]
k	Weighted factor [-]
σ	Standard deviation of detected signal amplitude [-]

1. Introduction

Steam is one kind of media that could transport energy such as in thermal power plants and in nuclear power plants for the electricity generation. The steam visualization in the plants can help to improve the energy and operation efficiency. The steam flow rate measurement is one of the solutions that can monitor the consumption, leakage and stagnation of steam. The orifice and vortex flowmeters are widely applied to measure the dry steam flow rate [1]. However, they are difficultly applied to measure the flow rate of wet steam under low pressurized condition since the droplets in wet steam attach to the surface of measurement instruments and this would disturb the flow rate measurement. Furthermore, the invasive flowmeters can cause pressure drop and this increases the wetness of steam. The ultrasonic clamp-on flowmeter only needs to attach on the outside of pipe wall for the flow velocity measurement [2]. A study of clamp-on ultrasonic flowmeter based on tuft method has been reported by our group [3]. However, the tuft method is not applicable in high wetness condition, because the ultrasound is attenuated by the condensed droplets in the steam. The acoustic scattering by droplets disturbs the ultrasound reaching to the sensor. By contrast, ultrasonic velocity profiler (UVP) which can measure the flow velocity profile by scattering echo from the reflectors is one of the solutions to overcome the high wetness [4]. The droplets in steam are employed as reflectors. However, the acoustic attenuation in steam is much higher than that in water and the sound velocity in steam is lower than that in water. The echo signal from droplets has low signal to noise ratio since the attenuation in steam. Thus, the air-coupled ultrasonic technique used in nondestructive inspection field has been considered to solve this issue [5,6]. The air-coupled ultrasound is developed for non-contact and non-destructive inspection through the air by improving the ultrasonic sensors and amplifier. The air-coupled ultrasonic sensors applies low-frequency ultrasound from 10 kHz to 1 MHz since the acoustic attenuation in air. The low-frequency air-coupled ultrasound has more spread beam and less reflected echo signal than high-frequency ultrasound.

Consequently, the objective of this study is to apply the developed UVP with air-coupled ultrasound to the steam flow measurement in high wetness condition. Focusing sensor is developed to overcome the beam spread by low-frequency air-coupled ultrasound. Besides, the signal processing for eliminating the noise from side lobe is applied to air-coupled UVP system.

2. Steam jet measurement system

The wavelength of ultrasound is one of the major parameters for tracer particle selection in UVP. The ultrasonic frequency depends on the maximum measurable length, spatial resolution and the particle size. For instance, higher frequency ultrasound is applied to shorter distance, higher spatial resolution, and smaller particles. By contrast, the lower frequency ultrasound is applied to the long distance, lower spatial resolution, and bigger particles. The lower ultrasound has advantage of the lower attenuation during propagation. The particle size should be selected around the quarter of wavelength [7]. Therefore, the ultrasonic frequency for the steam measurement depends on sound velocity of steam. The sound velocity in saturated steam is approximately 473 m/s in atmospheric pressure [8]. The sound velocity in water at room temperature is 1500 m/s that is 3 times of that in steam. Air-coupled UVP system is developed in order to overcome the gap of physical properties. The maximum measurable velocity of UVP depends on sound velocity c, ultrasonic basic frequency f_0, and pulse repetition frequency f_{prf} which is defined as following equation [7].