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3D ultrasonic propagation analysis in flow field using Finite Element Method.

有限要素法を用いた３次元流れ場中の超音波伝搬解析

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1. Introduction

Ultrasonic propagation is affected by flow field in a medium such as air or water etc. Especially, the propagation time, path and frequency are changed by the flow field. A flow meter makes use of these effects to measure flow velocity or volume. Sonar also uses these effects to measure not only location but also velocity of a movable body. In these ways, many measurement manufactures are developed by using these effects of flow field.

In this paper, we focus on the following three points. The first one is the method we adopt to introduce the flow effect into our FEM simulator, the second one is to show some 2D analyses, which are compared with theoretical solutions and finally we show 3D analyses of flow meter with and without flow field.

2. Theory

FEM is being adopted in an ultrasonic simulator, ComWAVE program package to perform time domain three-dimensional simulations for ultrasonic propagation. This software has been developing at ITOCHU Techno-solutions Corporation.

The ComWAVE is based on the following governing equation [1].

$$\rho \frac{\partial^2 u_i}{\partial t^2} - \frac{\partial \sigma_{ij}}{\partial x_j} - b_i = 0 \qquad (1)$$

Here, ρ is mass density, u_i is displacement vector, σ_{ij} is stress tensor, and b_i is body force vector.

In order to incorporate the flow field function with ComWAVE, we have adopted semi-Lagrange method which has two coordinates. The one is Euler-coordinates for physical quantities and the other is Lagrange-coordinates for solving the differential equation [2].

3. Application

Our test models applying the new function of flow field are shown in below.

In these test models, we have adopted the unrealistically high flow velocities in order to emphasize these effects.

1) Simulation for 2D ultrasonic Doppler effects in air.

The ultrasonic propagation in air is affected by the direction, strength and distribution of wind. We show these effects using 45kHz ultrasonic propagation in air as shown in Fig.1. The main results are summarized as following items:

1. The propagation time, path and frequency are changed by the wind.
2. The results of arrival time and center frequency for uniform flow are good agreement with theoretical solutions as shown in Fig.2(b). In addition, we see the waveform amplitude at upstream side is larger than downstream side in order to satisfy the energy conservation law.
3. The direction of propagation is bended by distribution wind.

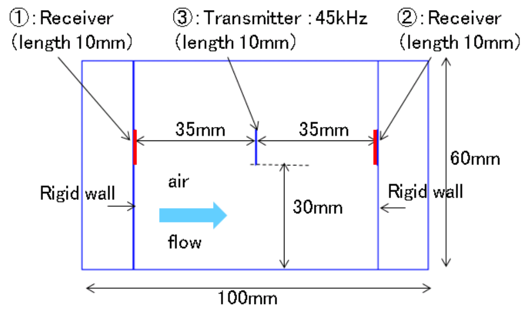
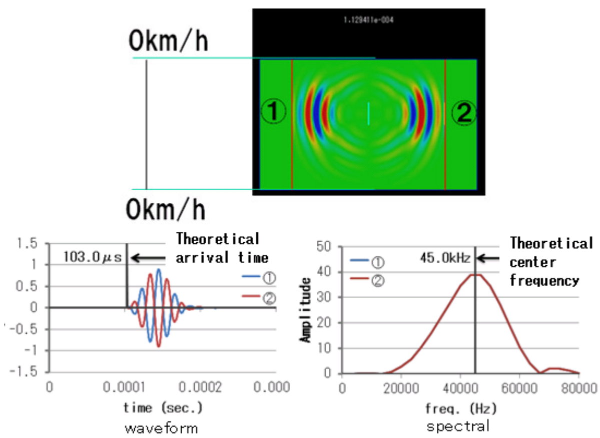
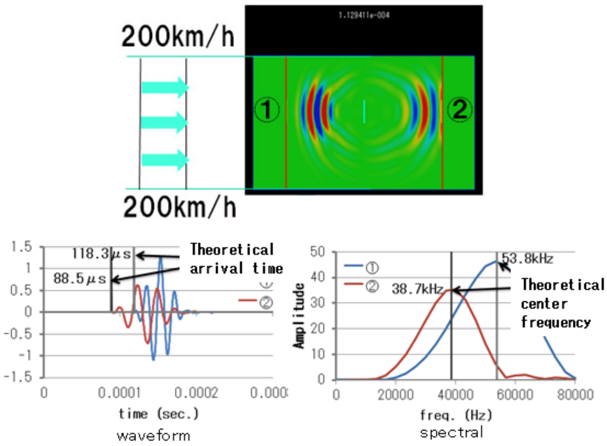


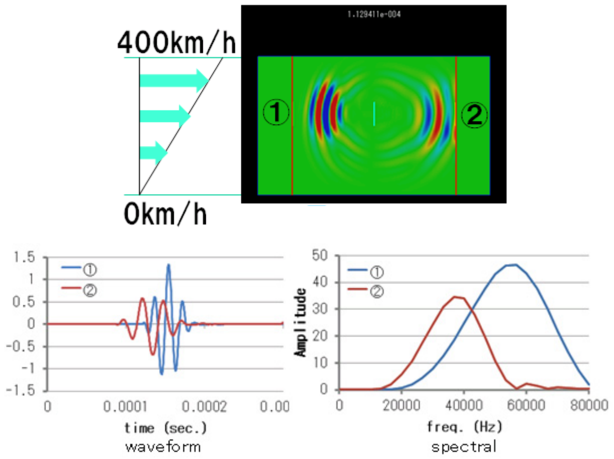
Fig. 1 2D ultrasonic simulation model with air flow.



(a) without flow



(b) with uniform flow



(c) with distribution flow

Fig. 2 2D ultrasonic simulation results with air flow.

2) Simulation for 3D ultrasonic flow meter

We apply the method to 3D flow meter model as shown in Fig.3. The main results are summarized as following items:

1. The echo arrival time at upstream side is delayed due to existing flow.
2. The echo amplitude at upstream side is detected with amplifying than without flow model.
3. The angle of the wave front in the pipe differs from without flow model.

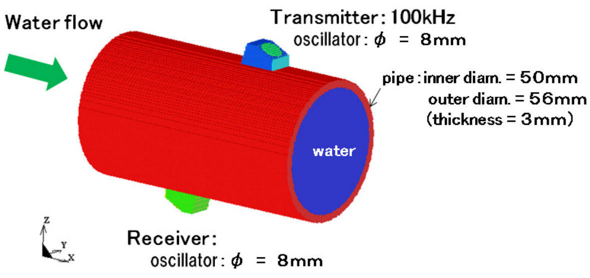
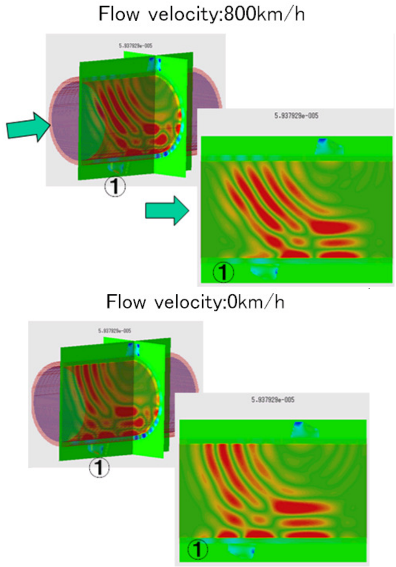
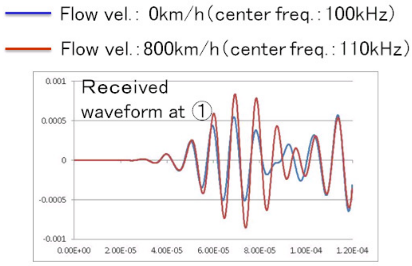


Fig.3 3D ultrasonic flow meter model with water flow



(a) Snap shots of ultrasonic propagations with and without flow field.



(b) detected waveform at ①

Fig.4 3D ultrasonic flow meter simulation results with water flow.

4. Summary

In order to incorporate flow field function with ComWAVE, we have adopted semi-Lagrange method which has two kind of coordinates. The one is Euler-coordinates for physical quantities and the other is Lagrange-coordinates for solving the differential equation [2].

We have shown these effects using 45kHz ultrasonic propagation in air and the results are good agreement with theoretical solutions. In addition, in order to see applicability to 3Danalysis, we have shown these effects using the 3D analysis of flow meter with flow field.

References

1. Ikegami Y, Sakai Y, and Nakamura H, "A Highly Accurate Ultrasonic Simulator Capable of Over One Billion Elements for Non-Destructive Evaluations",7th Int Conf on NDE in Relation on Structural Integrity for Nuclear and Pressurized Components.2010.
2. Takahashi S, Muramatsu K and Kimoto A,3D Transient Analysis of Ultrasonic Propagation in Flow Field Using Finite Difference Time Domain Method.,IPSJ SIG Technical Report 2008.