Abstract

Transit-time ultrasonic flow meter is a well established and widely used method for measuring flow of fluids. However, its application when multi-phase flow conditions occur remains to be a challenging task, particularly in industrial applications. The presence of the multi-phase flow typically violates the repeatability of the measurements and thus impairs the device accuracy. Development of new flow meter designs for these conditions based on a purely experimental approach is expensive both in terms of time and economy. An attractive alternative is the employment of a mathematical model.

In this work, a numerical model that simulates propagation of acoustic waves in ultrasonic flow meter measurement setups is developed. The underlying governing equations are modified first order stress-velocity equations of elastodynamics with additional terms to account for the effect of the background flow. Acoustic media are modelled by setting the shear modulus to zero. Spatial derivatives are approximated by a Fourier collocation method allowing the use of the Fast Fourier transform while the time integration is realized by the explicit fourth order Runge-Kutta finite difference scheme. The method is further extended by mesh adaptation techniques to accurately resolve acoustic scattering in complex geometries.

The presented numerical model is, to the best of the author's knowledge, the only pseudospectral model available in the open literature that solves propagation of acoustic waves in moving heterogeneous media.

The model is verified against analytical solutions and other numerical methods. Subsequently it is validated against experimental measurements in quiescent heterogeneous media. A direct comparison of the received waveforms is non-trivial due to high uncertainties of material properties in ultrasonic transducers. An alternative approach is presented in this work. The total received measured electrical and simulated acoustic energies, normalized with respect to propagation in a homogeneous medium, are compared instead. The energy losses as a function of increasing gas-void fraction are examined. A good agreement (error below 2.1 %) is found. The approach is afterwards used on a large set of experimental measurements conducted on an industrial multi-phase flow rig. It is demonstrated how the model can be used to give a good estimate of the signal deviation for a given gas-void fraction and size of the secondary phase inclusions.

The presented work is, to the best of the author's knowledge, the only study available in the open literature that discusses simulation of ultrasonic flow meters under multi-phase flow conditions and its comparison to experimental measurements to such extent.