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Void fraction measurement of the air-water two-phase flow in the sub-channel of a rod bundle geometry based on an impedance meter

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ABSTRACT

The research of two-phase flow is very important for the safe operation of nuclear reactor. However, measurement method is a limitation for the experiment investigation of the two-phase flow in rod bundle channel. To measure the average void fraction of a sub-channel in rod bundle geometry, a new impedance meter is developed. The sensor of the impedance meter is composed of twelve electrodes. Due to the special architecture of rod bundle channel, the sensitivity and linearity of the impedance meter are different for different combination schemes of electrodes. To find the best scheme for the impedance meter, some combination schemes are researched based on the distribution of electric field. Simulation and experiment methods are used to study the schemes. A best scheme is given at last, and an experiment is designed to prove the result.

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1. Introduction

Air-water two-phase flow is a common phenomenon in industry and our daily life. The characteristics of air-water two-phase flow, such as the void fraction, the pressure drop, the flow pattern and so on, play an important role in researching a system. For example, the investigation of the air-water two-phase flow in the rod bundle channels of nuclear reactor is important for the safe operation of nuclear reactor (Pham and Kunugi, 2016; Sadatomi et al., 2004; Tian et al., 2016; Zhang et al., 2017). There are two methods to study two-phase flow. One is numerical simulation (Li et al., 2017; Saad et al., 2017; Wei et al., 2017), the other is experiment. Numerical simulation method can be used to study two-phase flow without limitations of experiment environment. This method can provide any information you want. But the result correctness of numerical method need to be verified. On the contrary, experiment method can offer more credible result.

Measurement method is one of the restrictions for experiment, especially for the research of the two-phase flow in rod bundle channels. Although some measurement means have been developed for the measurement of the two-phase flow in rod bundle channels, much information cannot be measured. The existing measurement methods include electrical conductivity probe, impedance meter, wire mesh sensor, high speed camera (HPS), laser doppler velocimetry (LDV), dynamic particle tracking velocimetry (DPTV) and so on. Unfortunately, there are many application limitations for these methods. For instance, electrical conductivity probe can measure phase volume fraction, gas velocity and other information (Yang et al., 2012), but it also affects the flow field of two-phase flow; impedance meter can only get the global phase volume fraction of a cross section (Paranjape et al., 2011); wire mesh sensor can only get the phase volume fraction in the central point of rod bundle channels (Arai et al., 2012); the picture captured by HPS will be shielded by rods (Pham et al., 2015); LDV and DPTV have the same problem with HPS (Dominguez-Ontiveros and Hassan, 2014; Xiong et al., 2014). In general, though these measurement methods can measure some information of the two-phase flow in rod bundle channels, much other important information cannot be measured, such as, the average void fraction in a single rod bundle channel (sub-channel). To measure the average void fraction in a sub-channel, a new impedance meter is designed. However, due to the special architecture of rod bundle channel, there is a measurement precision problem for the new impedance meter. This paper will give a detailed description of the investigation of the impedance meter.

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2. Impedance meter

For the limitation of the space in a sub-channel, the sensor of the impedance meter is shared with an Electronic Resistance Tomography (ERT) device. The sensor is shown in Fig. 1. Twelve electrodes are installed on the rods around a sub-channel shown in Fig. 1(B). The parameters of the sensor is shown in Table 1. Some of the electrodes are tied together as an excitation electrode, while the other electrodes are tied together as a detection electrode. A sinusoidal voltage signal is applied to the excitation electrode. Then, with the changing of two-phase flow, the measured signal on detection electrode will change. The measured signal contains the information of the void fraction of two-phase flow. This is the principle of the impedance meter.

However, there are many combination schemes of the twelve electrodes as excitation and detection electrodes. The linearity and sensitivity of these schemes are different. To obtain a best scheme from these schemes, it is necessary to study the sensor. The working principle of the impedance meter shows that:

1. An electric field is established after excitation voltage signal is applied on the measurement area.
2. The electric field will be changed when two-phase flow is changing.
3. The voltage signal on the detection electrode will change with the changing of electric filed.

Then, we can know from the principle that the electric field can affect measurement result. The measured signal will change more at the same two-phase flow when electric field is strong. That is the reason of the sensitivity of the impedance meter. Similarly, if the distribution of electric field is uniform, the linearity of the impedance meter will be better. Therefore, the sensor can be investigated based on the distribution of electric field.

3. Different sensor schemes

3.1. Schemes

There are total 2^{12}-2 schemes to define the functions of the twelve electrodes (the schemes, that all the electrodes are used as excitation or detection electrodes, are excluded). To ensure the uniform distribution of electric field, only the schemes, that six electrodes are combined as an excitation electrode, are studied. Moreover, due to the requirement of symmetry for the excitation and detection electrodes, only three of these schemes are selected. They are shown in Fig. 2. These schemes are marked as scheme (A), (B) and (C). Simulation and experiment methods are used to study the electric field distribution of these three schemes.

Table 1
Parameters of the impedance meter sensor.

Parameter	Value (mm)
Rod diameter	9.5 mm
Rod pitch	12.6 mm
Electrode length	10 mm
Electrode width	1 mm

3.2. Simulation research

With the help of simulation method, we can obtain the distribution of electric potential and electric field in a sub-channel. Fig. 3 is the distribution of electric potential for different schemes. Scheme (A) shows that the distribution of electric potential is more uniform in the area along x direction compared with scheme (B) and (C). However, the change of electric potential is so slight that we cannot obtain more information. To get more information, the equipotential line of these three schemes are obtained in Fig. 4. These figures show that:

1. The equipotential line in the area along x direction in scheme (A) is the most uniform. The equipotential line in area F and G are not uniform in scheme (A).
2. The equipotential line in area A is not uniform in scheme (B). Then, the linearity of scheme (B) is worse than scheme (A) when void fraction is big, because big bubble can only go through from the center of sub-channel.
3. The equipotential line in area A, B, C, D and E are not uniform in scheme (C). Therefore, the linearity of scheme (C) is worst.
4. The equipotential line is dense in area H and I of the three schemes. These areas are more sensitive than the other areas. Thus, the sensitivity is better in small void fraction for all schemes. The reason is that small bubble usually go through around rods.

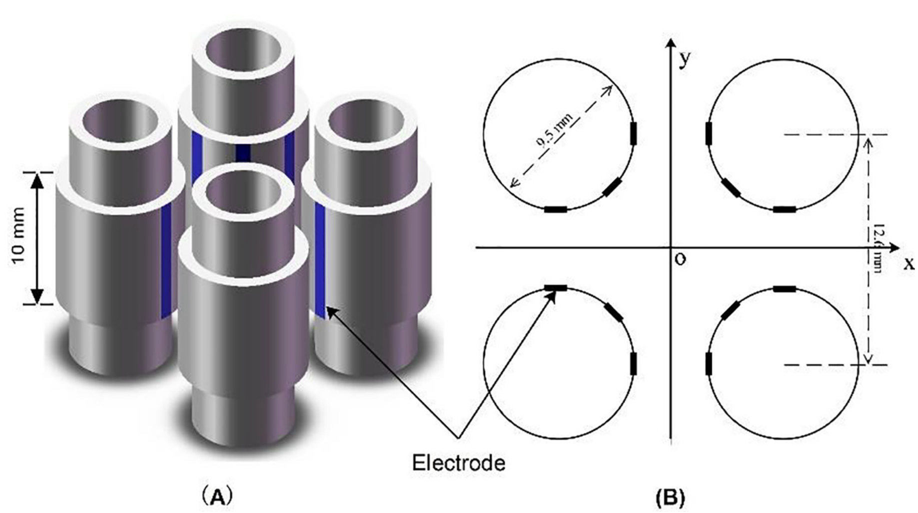

Fig. 1. Architecture of the impedance meter sensor.

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