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Development of Axial Tomography for Steam Explosion Study

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1. Introduction

Visual understanding of complicated system leads us often to the intuitive enlightenment of the invisible causes of the effect. When it is formulated based on the rigorous mathematics, the produced formula or correlation will be very useful in design and analysis of the engineering system. In this point of view, the tomography technology can be a tool to meet such a purpose. However, the traditional hard ray tomography using high energy radiation cannot meet the case due to heavy shielding structure which obstructs access of the sensing unit to the very complicated and limited space. Therefore, the recent development of the electric tomography is noteworthy in the application to the industrial process monitoring. It has the merit not only of low cost but also of easier access to the limited space than the hard ray tomography.

As a f unsolved issues in the severe accident, the steam explosion phenomena has been studied. It was observed that unlike the case of aluminum oxide, the magnitude of the steam explosion of the molten corium of the fuel pellet was not significant to make a severe damage to the system. However, still we have no detailed understanding on the propagation of the phenomena. In order to investigate the phenomenon, KAERI has been developed a test facility, TROI, to produce data of explosion such as the pressure sound wave and geometrical data of debris.

It was concluded that to understand the explosion three dimensional time sequential measurement of the steam and corium distribution in the water pool. Some institute is now developing a fast X-ray tomography method but its observation window is too small to deliver such data. KAERI and Han Dong University decided to develop a new tomography method to understand such an explosive phenomenon. The proposed method is so called "axial tomography" because it will determine the phase distribution image in the axial plane rather than the cross sectional plane of the conventional tomography.

It has two challenges in the engineering point of view:

- Open field problem: at least at some parts, for instant upper part or bottom part, no electrode will be mounted and it will allow the electric field propagates to the environment so that the sensitivity of the electric field will be reduced.
- In order to measure the steam and corium distribution, we need to develop the tomography which can distinguish water, steam, and corium.

In the present paper, the current state of the development of axial tomography will be represented.

2. Methods and Results

In this section some of the techniques used to develop the axial tomography are described.

2.1 System overview

Axial tomography system has two parallel electrode assembly as shown in Fig.1. Each side of the test section, four plates of electrodes were mounted.

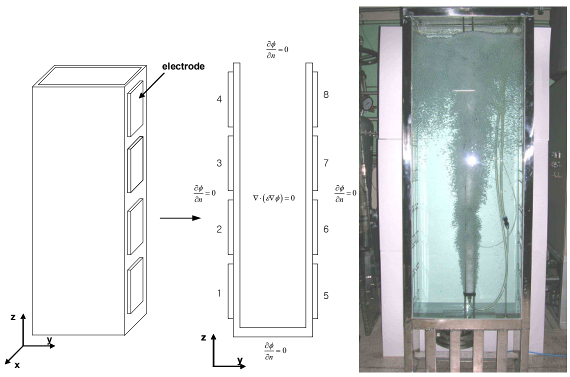

Fig.2 The control volume and electrodes to be analyzed and the test section constructed for this purpose.

Also, capacitance was measured in the level of femto farad level using a specially invented circuit. The whole data processing unit developed is shown in Fig. 3.

Fig.3 The axial tomography analyzer for data acquisition and electrodes switching.

2.2 Image Reconstruction

In order to produce the images inside the control plane, at first we need to determine the sensitivity matrix. For this purpose, we developed a computer code to determine the electric potential based on the finite difference method. Using the code, we determine the sensitivity matrix of the excited electrode pairs as shown in Fig. 4.

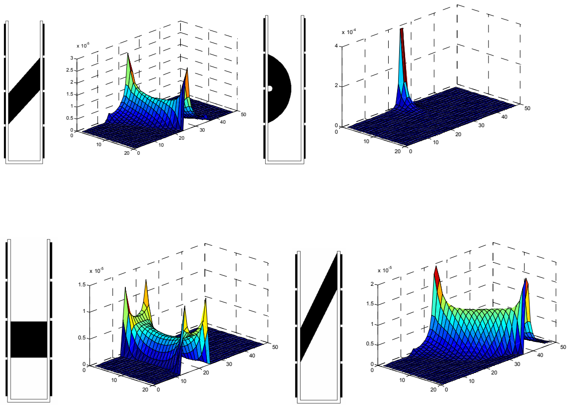

Fig.4 Some examples of the sensitivity matrix determined

The image is reconstructed in the way of reducing the error between the measured capacitance and estimated capaciatances:

$$E^2 = \sum_{i=1}^{7}\left(\sum_{j=1,j\neq i}^{7}(C_j^m - C_j^e)\right)^T\left(\sum_{j=1,j\neq i}^{7}(C_j^m - C_j^e)\right) \quad (1)$$

The least squarer optimization produced the relation as

$$\sum_{j=1,j\neq i}^{7} C_j^e = \frac{\iiint \varepsilon\, f\,dv}{\iiint \nabla f\,dv} = \underline{A}(f)e \quad (2)$$

Therefore, we can determine the distribution of the dielectric constant representing the phase distribution as:

$$e = \frac{\sum_{i=1}^{7}\left(\sum_{j=1,j\neq i}^{7} C_j^m\right)\underline{A}_i}{\sum_{i=1}^{7}\underline{A}_i^T\underline{A}_i} \quad (3)$$

The Jacobian A can be replaced by the sensitivity matrix S as

$$C_i^e = \underline{S}_i e \quad (4)$$

Just incase of the singulatity in the sensitivity matrix we add up some regularization parameters named Tikonov regularization.

2.3 Results

Unfortunately, the present method produced very poor images especially it has a large distortion at the water surface as shown in Fig. 5. Especially the calculated capacitance with the sensitivity matrix and measured data show a big differences which propages into the analysis to produce such a problem

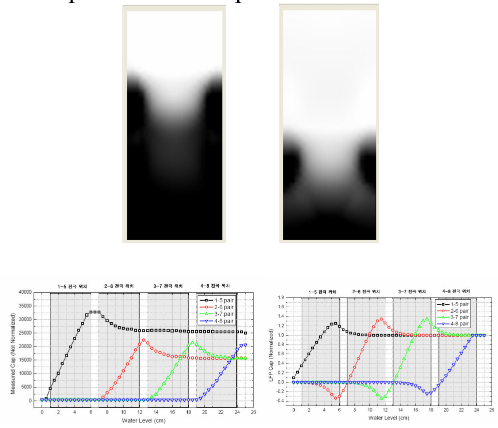

Fig.5 Distorted images of the axial tomography and the field results

However, we made a remedy using a special algorithm by emphasizing the sensitivity matrix and tune the regularization parameter. The results were more promising to be applicable to the study of steam explosion as shown in Fig, 6.

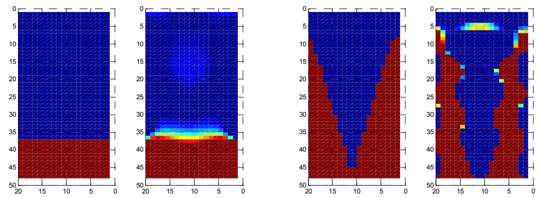

Fig.6 Reconstructed images of the axial tomography with the new method

3. Conclusion

An axial tomography is proposed for the study of the rapid transient, steam explosion. We proposed the structure of electrodes and applied proper hardware to sense the capacitance in the change of excitement and switching. It was found that the conventional inverse algorithm based on the linear sensitivity matrix fails in the estimation of the water level no matter what kinds of iterative regularization methods are applied. However, optimization of the regularization parameter gave the more promising results.

Acknowledgement

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REFERENCES

[1] J.Y. Lee, Interim report: A study on Axial Tomography, Lab of electro-TH, Han Dong Univ. 2006.