Development of Electromagnetic Analysis Model for IV-CEAPI

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1. Introduction

There have been demands for an in-vessel CEDM (Control Element Drive Mechanism) to fundamentally eliminate the rod ejection accident, and the in-vessel CEDM entails in-vessel CEAPI(Control Element Assembly Position Indicator).

There are many different types of position indicators such as reed switch type, ultrasonic type, solenoid type, etc. Through an analysis of strengths and weakness of those types, solenoid type was selected for an IV-CEAPI[1]. Although solenoid type CEAPIs have been used world-wide, the IV-CEAPI is to be very different from the conventional designs due to its harsh operating environment. The concept of the IV-CEAPI is simple as shown in Figure 1. The coil is made of mineral insulated wire to be able to operate inside reactor vessel. The CEA is connected to the shaft which is made of ferromagnetic material. As the CEA position varies, the inductance variation is detected by the inductance meter located outside the vessel. Unlike the conventional ones, the IV-CEAPI used only one coil to eliminate coil connection point and electric components inside vessel.

Since the IV-CEAPI concept design uses the analog inductance value directly, it is important to predict the characteristics of the inductance curve. In this paper, finite element model of a solenoid type CEAPI is developed to calculate its inductance.

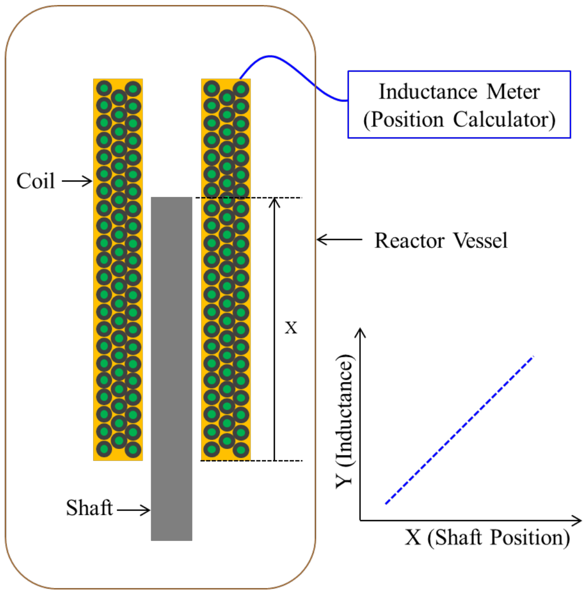


Fig. 1. IV-CEAPI Concept

2. Solenoid Sample Test

A sample solenoid was manufactured for a test. Table I shows the specification of the solenoid. Inductance of the solenoid was measured at 1V and 20Hz by a commercial LCR meter. The measured inductances were 2.6mH and 22.8mH for shaft position (X, defined in Figure 1) of zero and 700mm, respectively.

Table I: Specification of a sample solenoid

Length of the coil	700 mm
Coil I.D	60 mm
Coil O.D	62 mm
Shaft O.D	15 mm
Number of turns	702

3. Inductance Calculation

3.1 Hand calculation

Inductance of a solenoid coil is calculated by the well-known equation of (1). Inductance of the sample solenoid was calculated by substituting the parameters of Table I and permeability(μ) of air into the equation, which represents the shaft position of zero. The calculated inductance is 2.5 mH, which agrees well with test result.

$$L = \mu \times N^2 \times A \div l \quad (1)$$

However, this hand calculation is applicable only to zero position. For non-zero position, uncertainty increases due to the non-linear characteristic of permeability and frequency dependent electromagnetic phenomena such as eddy current effect.

3.2 FE Modeling

Finite element model was developed as shown in Figure 2 with Maxwell2D. The model consists of shaft, coil and coil spool. Electric conductivity of 1.75e6 Siemens/m and 1.39e6 Siemens/m was input for the shaft and coil spool, respectively, to consider eddy current effect.

Permeability of the shaft was set to have a linear value instead of the actual BH curve because using BH curve has so much uncertainty in calculation of inductance at such the weak magnetic field. The relative permeability of the shaft was determined to be 80 after iterative tuning process to match the calculated inductance value with the test result for shaft position of 700mm.

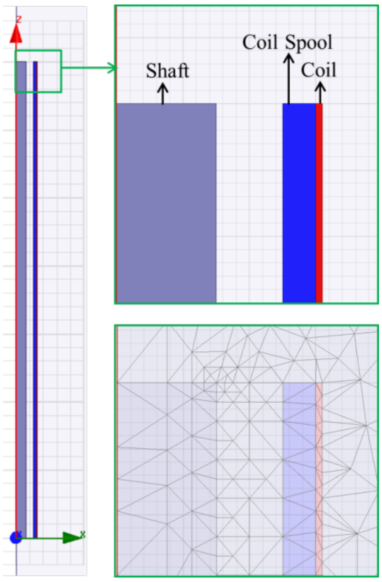


Fig. 2. Solenoid Model

3.3 FE Analysis

Analyses were performed for various position of the shaft. Analysis conditions such as current, frequency were set to be the same as the test condition.

Figure 3 shows the comparison of the calculation and test results of inductance. The analysis results agree well with the test result for overall range of the shaft position. Also, the analysis result well-describes the non-linear part of the curve, which is an important issue in terms of IV-CEAPI design.

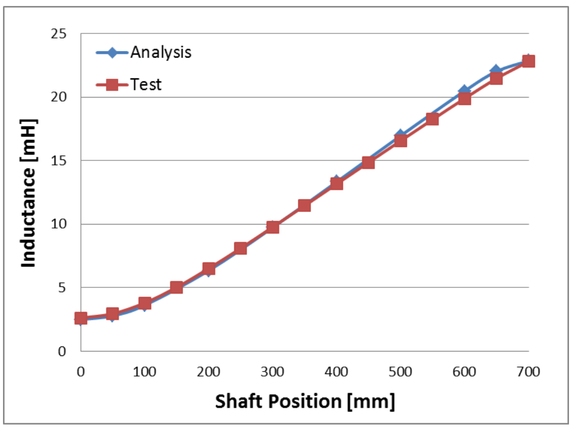
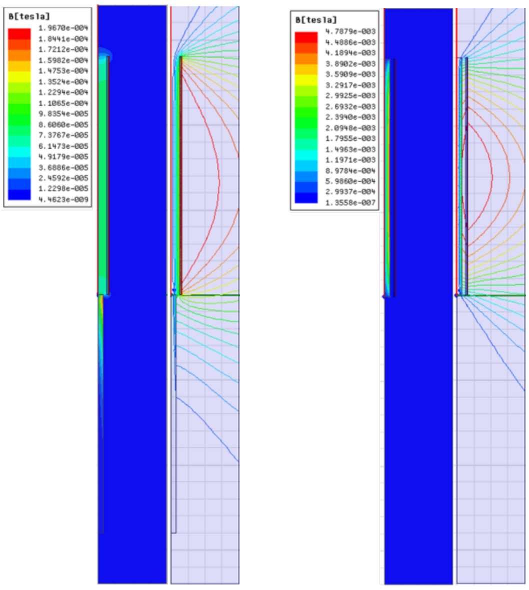


Fig. 3. Analysis Result

Figure 4 (a) and (b) show the magnetic flux distribution for shaft position of zero and 700mm, respectively. Figure 4 (b) shows that flux density is more concentrated in the outer region of the shaft due to eddy current effect unlike Figure 4 (a).



(a) shaft position zero (b) shaft positon 700mm

Fig. 4. Flux distribution

4. Conclusions

A finite element model was developed to calculate inductance of the solenoid type IV-CEAPI. The model considers eddy current effect to calculate frequency dependent inductance value. Analyses were performed to produce an inductance curve to the shaft position. The calculated curve shows good agreement with the solenoid sample test results. This analysis model will be used to study various characteristics of solenoid type IV-CEAPI.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Power Core Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 20131510101680)

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[1] Jang Yongtae, Park Jinseok, Lee Myounggoo, Cho Yeonho, Kim Hyunmin. Technical Survey and Feasibility Review for Development of IV-CEAPI, Proc. of the Korean Nuclear Society '16 Spring Conference, 2016