Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006
2006 Korean Nuclear Society Spring Meeting

Finite-Element Analysis of the Electromagnetic field of the Magnetic Jack Type Control Element Drive Mechanism

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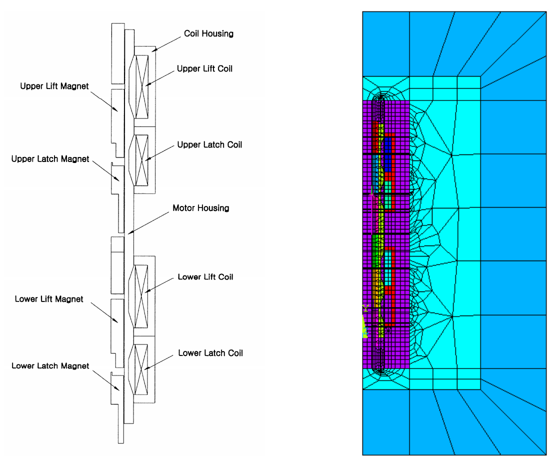
1. Introduction

The magnetic Jack Type Control Element Drive Mechanism (CEDM) is an electro-mechanical device to provide a controlled linear motion for the control element assembly (CEA). Since the CEDM is directly related to the safety of the reactor, it has been a very important issue to monitor the CEDM operation. The CEDM operation has been monitored by comparing the detected current trace to the normal one. Diagnosis of the CEDM has been made by experience, which is why it is sometimes very difficult to make right judgment. Therefore, there has been demand for developing a reference current trace to diagnose the CEDM operation by theoretical approach.

Numerical analyses have been used for the design of the CEDM for various static cases [1, 2]. The transient analysis of the electromagnetic field of the CEDM using FEM has been performed recently [3]. However, it has never been applied for practical uses such as diagnosis of the CEDM.

In this paper, transient analysis of the electromagnetic field of the CEDM using FEM is carried out. The current trace of the CEDM latch coil is obtained as a result. The simulation result is compared with the test result to verify the applicability. Also, abnormal cases are assumed and simulations for the cases are carried out to obtain the current traces. The results of the abnormal cases are reviewed to check the possibility of FEM analysis as a way to develop a reference current trace for CEDM diagnosis.



(a) Schematic drawing of CEDM (b) FE model

Figure 1. Axisymmetric model of the CEDM

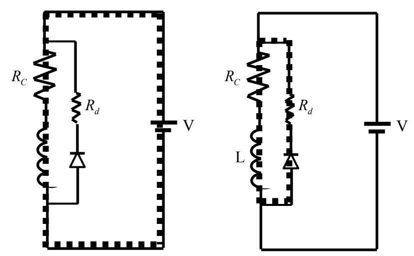
2. Modeling and analysis

A 2D axisymmetric model of the CEDM has been developed using ANSYS [4]. Figure 1 (a) shows all the major components of the CEDM which should be considered in electromagnetic analysis. Figure 1 (b) shows meshed model of the CEDM. The B-H curves of the coil housing, motor housing and the magnets have been obtained by a test to consider the nonlinear characteristics of the materials.

The driving circuit has two different current loops depending on the on/off condition of the power supply as shown in Figure 2. Therefore, the electric circuits are represented by the following equations of (1) and (2) depending on the on/off condition. R_c, R_d and ϕ is the coil resistance, dissipation resistance and flux linkage of the coil, respectively. Voltage drop by the freewheeling diode is neglected because of its relatively small magnitude.

$$R_c I + \frac{d\phi}{dt} = V \quad \text{(Voltage on)} \quad (1)$$

$$R_c I + R_d I + \frac{d\phi}{dt} = 0 \quad \text{(Voltage off)} \quad (2)$$



(a) Voltage on (b) Voltage off

V: Power Supply
L: Inductance of the coil
R_C : Resistance of the coil
R_d : Dissipation Resistance

Figure 2. Electric circuit to drive the CEDM

In this paper, only the latch coil is considered and the other three coils are neglected to simplify the problem. The actual input voltage has a ripple since it is derived from rectification of 3-phase AC voltage source. However, it has been modified to an equivalent voltage profile as shown in Figure 3. The gap and release spring between the lift magnet and latch magnet are modeled for the mechanical part.

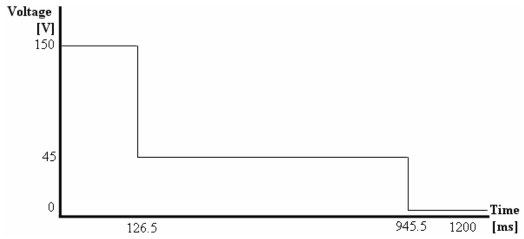


Figure 3. Input voltage profile of the CEDM

Simulations are performed for a normal case and abnormal cases to obtain the current trace. Abnormal cases are assumed to have debris between the lift magnets and latch magnet so that an engagement of the latch to the CEA does not occur possibly, which is a serious malfunction of the CEDM. The thickness of the debris for the abnormal cases is assumed to be 0.764mm, 1.524mm and 2.286mm.

3. Results and discussion

Figure 4 shows the simulation results, the current trace of the CEDM latch coil. The analysis result agrees well with the test result of Yong-Gwang NPP 5&6 in general although the simulated current trace has no ripple unlike the test result due to the simplified voltage input. Engagement motion of the latch magnet occurs when the current rises up to 7.6A according to the simulation result, which has a 2.6% error with the test result, 7.8A. The peak value of the current is 13.1A, which has an 11.0 % error with the test result, 11.8A. Since the engagement of the latch magnet occurs earlier than the one in the test, it has a longer time until the input voltage is changed to low voltage so that the peak value of the current is higher than the test. The result verifies the applicability of the transient analysis of the CEDM using FEM.

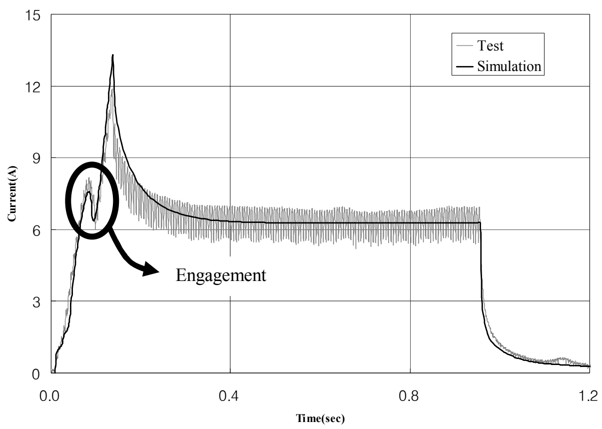


Figure 4. Current trace of the CEDM latch coil

Figure 5 shows the current trace of the CEDM latch coil for the various abnormal cases assumed above. Although the current traces look similar in general, they show recognizable differences during the engagement motion. The current drop reduces as the thickness of the debris increases. As the thickness of the debris increases, the distance that the latch magnet can move is reduced so that less back EMF is prduced. As a result, the amount of the current drop is reduced.

Theses results present that the transient analysis of the CEDM using FEM describes the abnormal state of CEDM precisely as well as the normal state, which implies that it is possible to develop a reference current trace of the CEDM coil for CEDM diagnosis by FEM.

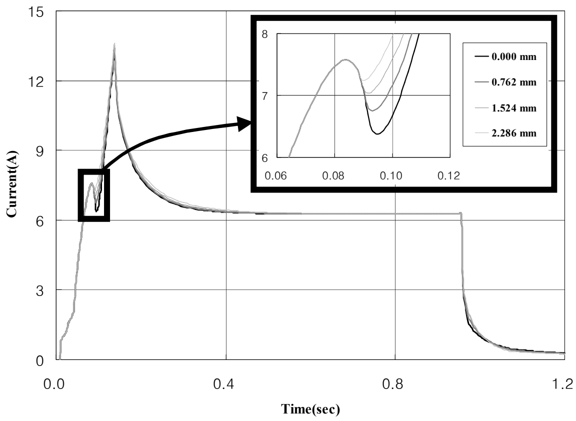


Figure 5. Current traces of the CEDM latch coil for various thickness of the debris in the gap.

4. Conclusions

The finite element model of the CEDM was developed including electrical equation of the drive circuit and mechanical motion. The transient analysis has been carried out to obtain current trace as a result. The trend of analysis result agreed well with the test result, which verifies the applicability of the developed model. Malfunction of the CEDM was assumed and simulated to obtain the current trace. The assumed malfunction affected the current trace significantly. All these result implies the possibility of FEM analysis as a way to develop the reference current traces for CEDM diagnosis.

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