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Electromagnet Response Time Tests on Primary CRDM of a Prototype Gen-IV SFR

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1. Introduction

The conceptual design of a prototype SFR (sodium-cooled Fast Reactor) with 150MWe capacity was begun in 2012 through the Korea national long term R&D project by KAERI. The prototype SFR has six primary control rod assemblies (CRAs) and three secondary shutdown assemblies [1, 2]. The primary control system is used for power control, burn-up compensation, and reactor shutdown in response to demands from the plant control or protection systems.

This paper identifies the electromagnetic response characteristics of the electromagnet of a primary control rod drive mechanism (CRDM) used for the reactor scram function. The test measures the electromagnet response time required to release an armature from a stator controlled by a loss of an electromagnetic force on an armature after shorting a power supply to an electromagnet coil. A simple electrical circuit for measuring the response time is configured. These tests are carried out while changing the electromagnet core material, an assist spring, and an armature holding current.

2. Test apparatus

The test device consists of an electromagnet and a surrounding case, a support structure, an armature associated with a drive tube, dummy masses, an assist spring to accelerating the fall of the driving tube, and a power supply, as shown in Figs. 1 and 2.

An S10C of a ferrite-based material is used as both the electromagnet stator and armature cores. An SS410 of a martensite-based material is adopted for the inner core and armature, as shown in Table 1. Several addition masses in the range of 20 kg to 70 kg are used as the traction loads of the electromagnet.

The supply current to the coil is up to 15 A. An assist spring with a stiffness of 34 kN/m is optionally mounted in a compressed state of 5 mm. The length of the assist spring in the test is 45 mm.

3. Measuring circuit of electromagnet response time

An electrical circuit for measuring an electromagnet response time is shown in Fig. 3.

The circuit consists of a directional diode and a resistor, and the circuit is connected to both ends of the power supply line. As the power is connected to the electromagnet coil, there is no current flow on the resistor because of a reverse voltage on the diode.

When the power supply to the electromagnet coil is switched off, a reverse voltage on the coil is generated by a magnetic flux change in the electromagnet, and a current then starts to flow in a forward manner in the diode and makes a voltage difference in the resistor. The current generated in the electromagnet is gradually decayed after the first voltage peak, as shown in Fig. 4. When a residual electromagnetic force is less than the weight hanging on the armature, the armature is self-departed from the stator. Then, a flux change generated by the moving armature occurs in the electromagnet once again, the current increases, a second voltage peak occurs in the resistor, and the magnetic flux is decayed out as the current becomes smaller.

Two voltage peaks retrieved from the records of the voltage hysteresis across the resistor match the instant of switching off the power, and the starting moment of leaving the armature from the stator, respectively [3, 4]. Therefore, the difference in time between the two peaks is an electromagnet response time.

4. Test content

Electromagnet response tests were performed to identify the variables that effect the electromagnet response characteristics of the control rod driving system. The test parameters are as follows:

- Armature holding current
- Electromagnet core material (S10C, SS410)
- Assist spring on/off
- Holding dummy mass (22.3 – 72.3 kg).

Electromagnet response tests, classified by eight kinds of tests, as listed in Table 1, are carried out. A current is supplied to an electromagnet coil in order to pull an armature from an initial gap of 10 mm, and after a few seconds, a reduced holding current is supplied on the coil to hold the armature. These tests are performed at room temperature.

5. Test results

The test results are summarized in Fig. 5. The test parameter effects confirmed through the tests are described as follows.

5.1 Armature holding current effect

The current magnitude on the coil must be adjusted to keep a traction load according to the dummy mass that is combined with the armature. The electromagnetic response time is proportional to the residual magnetic force. As shown in Fig. 5, it was found that the electromagnetic response time is proportional to the armature holding current regardless of the holding mass size and whether or not an assist spring is installed.

5.2 Electromagnet core material effect

Tests using the S10C material for both the stator and armature are given in test types 1 through 4 in Table 1, and those of the SS 410 material for the inner core and armature are given in test types 5 through 8. As shown in Fig. 5, for the case of using the S10C material, the response times are in the range of at least 0.21 to 0.27 seconds regardless of the holding mass size and whether or not an assist spring is mounted.

For the case of using the SS410 material, on the other hand, the minimum response time is shortened by 0.13 to 0.14 seconds at the armature holding current conditions. The response time for the S10C material is longer because the magnetization residual force of the electromagnet core is left for a while. It is not adequate to use the S10C material as an armature core.

5.3 Assist spring effect

An assist spring (34 kN/m) is combined with three types of tests (index S10C-20S, S410-70S, and S410-20S). The armature holding current has to be larger than 1.2A to install an assist spring, as shown in Table 1.

As shown in Fig. 5, when comparing the test kinds of S10C-20 and S10C-20S, the response time is shortened to 0.21 seconds from 0.25 seconds. Based on the test results for test types 7 (S10C-20) and 8 (S10C-20S), and for test types 5 (S410-70) and 6 (S410-70S), the installation of an assist spring on an electromagnet does not effect the reduction of the response time

5.4 Holding load effect

The effect of the holding mass (22.3 kg, 72.3 kg) on electromagnet traction loads also shows a similar trend as those for the assist spring. When the minimum response times for test types 2 (S10C-70-2) and 3 (S10C-20), test types 5 (S410-70) and 7 (S410-20), and test types 6 (S410-70S) and 8 (S410-20S) are compared with each other, the difference in the holding mass effect on the minimum response time is slight.

The armature holding current must be large as the traction load increases, and a large holding current makes the residual magnetic force larger, thereby making the response time longer.

6. Summary

The main factors influencing the test parameters on the response are found to be the armature holding current for holding the armature loads, and the material type of the electromagnet cores.

The minimum response time is 0.13 seconds in the case of using SS410 material as an armature, while the S10C material as an armature has a response time of 0.21 seconds.

Electromagnet response time characteristics from the test results will be evaluated by comparing the precise moving data of an electromagnet armature through the use of a high-speed camera and a potentiometer in the future.

The final acceptability of the electromagnetic response time data obtained by these tests will be evaluated through a future planned drop test because the control rod drop time should be within 1 second including the electromagnet response time.

Table 1 Test types and armature holding currents

Tests: Kind	Tests: No.	Index	Core mat.	Assist spring	Hold-ing mass (Kg)	Hold-ing current (A)
1	4	S10C-70-1	Stator (outer, inner, and top cores) : S10C Armature : S10C	Non	70	1.18~2.5
2	6	S10C-70-2		Non	70	1.1 ~2.0
3	2	S10C-20		Non	20	0.7~0.8
4	4	S10C-20S		34 kN/m	20	1.2~6.0
5	10	S410-70	Outer, top cores : S10C Inner core, Armature : SS410	Non	70	1.17~1.7
6	6	S410-70S		34 kN/m	70	1.6~3.0
7	8	S410-20		Non	20	0.7~1.5
8	5	S410-20S		34 kN/m	20	1.2~3.0

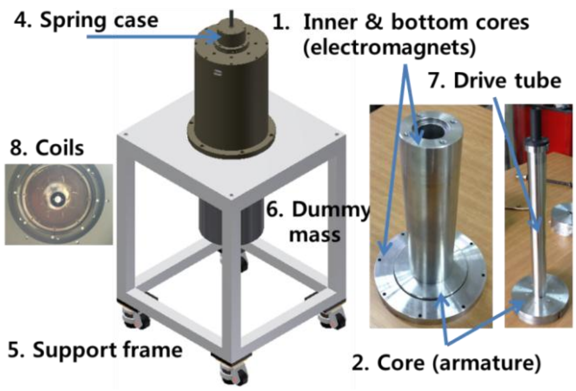

Figure 1 Test facility components

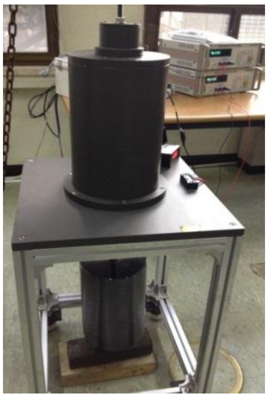

Figure 2 Test device picture

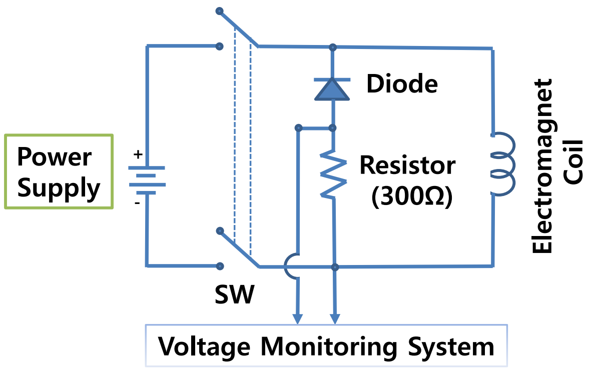

Figure 3 Electrical circuit measuring the response time

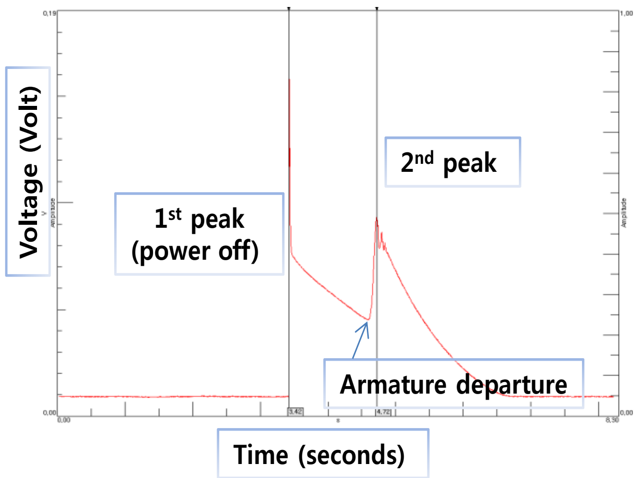

Figure 4 Typical voltage monitoring data on the resistor

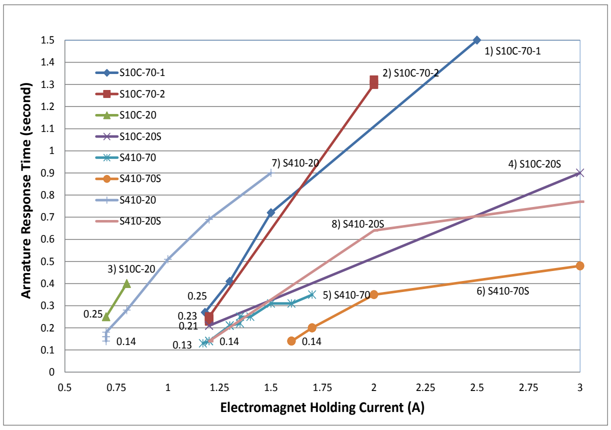

Figure 5 Electromagnet response time vs. armature holding current

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