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Performance and Endurance Tests of the Top-mounted CRDM for JRTR

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1. Introduction

A control rod drive mechanism (CRDM) is a device to control the position of a control absorber rod (CAR) in the core by using a stepping motor which is commanded by the reactor regulating system (RRS) to control the reactivity during normal operation of the reactor. The top-mounted CRDM driven by the stepping motor for Jordan Research and Training Reactor (JRTR) with plate type fuels is under development in KAERI. Based on the proven technology of the design, operation and maintenance for the research reactor, HANARO, the CRDM for JRTR has been optimized by the design improvement from new experience and information [1-3]. The CRDM for JRTR is classified as a safety class 3, a quality class Q and a seismic category I with the role of the reactivity control and the reactor shutdown system. Thus, it is necessary to verify the performances and the structural integrity for active components. This paper describes the test results to verify the stepping/drop performances and the endurance for a prototype CRDM. The performance qualification tests are carried out at the full scale full core test rig simulating the actual reactor's conditions. The test results of the CRDM met the performance requirements.

2. Structure Description

The JRTR is a pool type reactor with 5~10MW power which is open to the atmosphere. The reactivity control mechanisms of this reactor consist of four CRDMs and two second shutdown drive mechanisms (SSDMs) as shown in Fig. 1.

The CRDM is composed of a CAR, a CAR guide tube, carriages, tracks, a tie rod, and a drive assembly as shown in Fig. 2. The CAR is a square tube with the neutron absorbing material made of Hafnium. The actuation of the stepping motor in drive assembly is rigidly transferred to the CAR through the carriages and linkage mechanism. There are various universal joints on the connection points to improve the driving or drop performance of the moving parts. The CAR and moving parts are guided by the CAR guide tube in the core and tracks installed on the upper guide structure. The CAR guide tube is an aluminum square tube to guide the CAR and is mounted to the grid plate by rotating the cup with threading. The major material of the components of the CRDM is stainless steel except for the CAR and the CAR guide tube.

During normal operation of the reactor, the position of the CAR is controlled by a stepping motor commanded by the RRS. All four CARs drop by gravity into the core by de-energizing the electromagnets when a reactor trip is required by the reactor protection system (RPS) or the alternate protection system (APS). There is a proper hydraulic damping mechanism on the drive assembly to absorb the impact due to the CAR drop. The CARs also drop under the abnormal conditions such as loss of the electromagnet power, low-low level of pool water, or the set point of a seismic event. The position of the CAR is monitored by the duplicated indicators such as a rotary encoder attached to the stepping motor and a linear transducer attached to the dry well which moves together with the CAR. There are two upper limit and lower limit switches to detect the travel limits. There is a reset switch to detect the engagement of the electromagnet in the dry well.

A prototype CRDM is fabricated for the performance and the endurance qualification tests with the same design, materials, fabrication procedures, and quality class as the production units.

3. Test

3.1 Design and Test Requirements

The several requirements related to the performance of CRDM are as follows;

- CAR drop time : < 1.5 sec (before damping),
  < 3.0 sec (including damping)
- Initial delay time : < 0.15 sec
- Positioning error of CAR : < ±5 mm
- Drop impact : < 10 g
- CRDM shall maintain the structural integrity without excessive wear during endurance tests.
- Test rig shall adapt a full set of CRDM and SSDM, and simulate reactor operating parameters of flow, pressure and temperature.

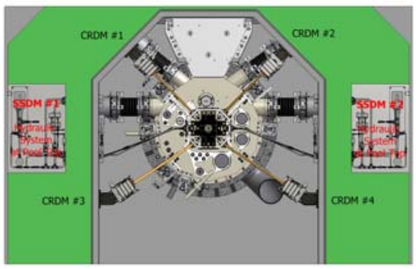

Fig. 1 Layout of the CRDMs and SSDMs

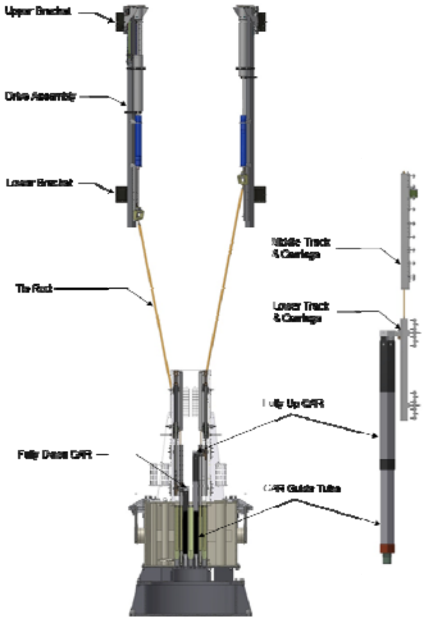

Fig. 2 Overall view of the CRDM

3.2 Test Facility

The test rig called as 'Full Scale Full Core (FSFC) test rig' is designed and fabricated for the performance and endurance tests of CRDM. It consists of an outlet plenum, grid plate, core support structure, pool and upper guide structure (UGS) as shown in Fig. 3. One set of CRDM and one set of SSDM are installed in this test rig. The core configuration is full size which is the same as the core for the real reactor structure. Dummy fuel assemblies and dummy beryllium with same configuration and weights are installed in the core. The height is also the same as the real reactor structure assembly and pool.

The test rig has the instruments and the control system to check the test conditions and the results of commissioning. The commissioning of the test rig and the functionality check of CRDM is completed before the performance and endurance tests.

3.3 Test Methods and Procedures

All tests for the CRDM are performed in accordance with the test procedures, and the test sequence is summarized as below.

1) Installation of CRDM
2) Commissioning test
3) Functionality check of CRDM
4) CAR drop performance test
5) Stepping performance test
6) Endurance test (drop of total 2000 times, motor test with hunting motion of 60 times)
7) Visual and dimensional inspection of CAR and CAR guide tube

Fig. 3 Full scale full core test rig

After the installation of CRDM, the commissioning test for the test rig is carried out to verify the test conditions such as flow rate, pool water temperature and water level. The functionality check is performed for a human and machine interface (HMI) system and sensors such as a stepping motor, limit and reset switches, a linear transducer and an electromagnet on the drive assembly.

The drop and stepping performance tests are to demonstrate that the CRDM can drop within the specified time and move the specified distances at the specified rates without mechanical malfunction. The CAR drop test is performed by de-energizing the power of an electromagnet at several heights (330, 440, 460, 600 and 650 mm). The drop time and impact value are obtained from the linear transducer and the accelerometer, respectively. The test for a stepping motor includes the verification of the stepping and the endurance performances. The difference between command signal for the driving of motor and encoder's output signal is checked for following four cases; (1) unidirectional sequence test, (2) advance & reverse sequence test, (3) complex sequence test, (4) hunting motion for the endurance test.

The endurance test of CRDM is to demonstrate the requirements for drop time, stepping performance and structural integrity for the drop of 2,000 times. Each test is performed 1000 times under the flow conditions of 5 and 10 MW. The drop time and impact value are recorded every 200 cycles. The endurance test of motor is carried out with the hunting motion as listed in Table 1. After the endurance test, the CAR and CAR guide tube of CRDM are dismantled from the test rig, and inspected to check the wear or damage due to the contact and the drop.

Table 1 Hunting motion for motor's endurance test

Steps/ cycle	Cycles	Steps/ cycle	Cycles	Steps/ cycle	Cycles
-15	20	-4	1,695	7	876
-14	36	-3	1,950	8	650
-13	80	-2	2,155	9	463
-12	132	-1	2,288	10	317
-11	208	0	2,334	11	208
-10	317	1	2,288	12	132
-9	463	2	2,155	13	80
-8	650	3	1,950	14	36
-7	876	4	1,695	15	20
-6	1,136	5	1,416	Total Cycles : 29,178	
-5	1,416	6	1,136		

4. Results and Discussion

4.1 Performance Test

The drive assembly of CRDM has many instruments to check and control the behavior of a CAR by using a stepping motor. The function for these instruments is checked and recorded according to the procedure and the checklist before the main test.

Table 2 presents the drop test results of CRDM at 5MW condition. The pure drop means the distance from the top to the starting point of damping (80mm from the fully inserted position of CAR). The drop times increase with the increment of the drop height. The test results show that the pure and full drop times of CAR meet the specified requirements of 1.5 and 3.0 seconds before and after the damping, respectively.

The impact values at the starting instant of damping are measured using the water proven accelerometer. The maximum acceleration is 4.0g lower than the design requirement, 10g.

Table 2 Summary of drop performance test results

Drop Height (mm)	Drop Time *(sec)		Impact (g)
	Pure	Full	
330	0.71	1.19	4.0
440	0.78	1.26	3.3
460	0.80	1.30	3.7
600	0.92	1.42	3.8
650	0.97	1.52	2.9
* Include the initial delay time, 0.3sec			

Fig. 4 shows the drop curve of CAR for 650mm full stroke height. The results meet the requirements of drop time before and after the damping. However, the initial delay time which designates the time from the instant the magnet power switch is actuated to the instant the CAR leaves it's parking position is measured as 0.3sec. The delay times should be less than 0.15sec which is assumed in the safety analysis. It has been confirmed that the reason of considerable delay is AC-type electromagnet for JRTR. Thus, we change the electromagnet from EM-R3.5 110VAC to EM-R3.5 12VDC with the same geometrical dimensions after the endurance test. Actually, the test results with the DC-type electromagnet being used for HANARO show lower than 0.1sec repeatedly.

Fig. 5 shows the drop curve of CAR using a DC-type electromagnet for the same conditions with Fig. 4. The initial delay time is 0.07sec shorter than 0.15sec considered in the safety analysis. The drop times and impact meet also the design requirements.

Table 3 presents the stepping performance results of CRDM for the advance & reverse sequence motions. The stepping motor of CRDM moves the specified distances at the specified rates without mechanical malfunction. It is found that there are no the differences between the command signal for the motor and the output signal of the encoder. The results of the stepping motor for the unidirectional and complex sequence tests as well as advance & reverse sequence tests show also the good stepping performances without a malfunction.

Table 3 Stepping performance test results for advance and reverse sequence motions

Description	Total Steps	Linear Trans. Position	Command Position	Encoder Position	Error
Sequence Upward	53,730	649.74	32,280	32,280	0
Sequence Downward	53,730	0.0	-32,280	-32,280	0

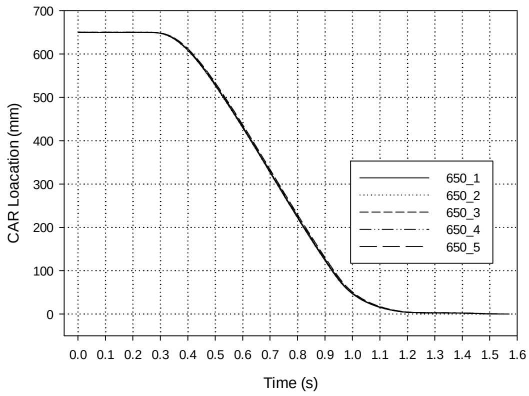

Fig. 4 Drop curve of CAR using AC-type magnet

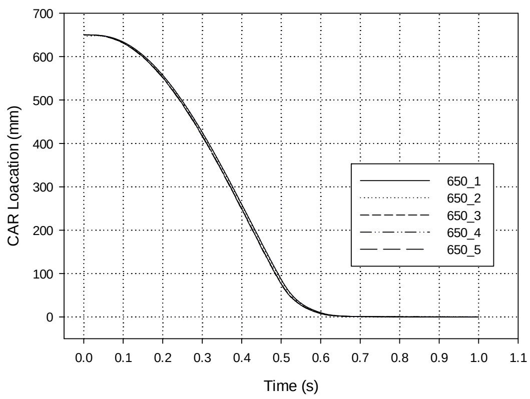

Fig. 5 Drop curve of CAR using DC-type magnet

4.2 Endurance Test

The drop endurance test of CRDM is performed for 2000 times (each 1000 times for 5MW and 10MW) at 650mm drop height. Fig. 6 shows the drop times for the drop endurance of 1000 times under the flow condition of 10MW. The full drop times have some fluctuation in the range of 1.20~1.74 seconds at the latter half of the period, but these are lower than 3.0sec of the requirement with the good drop performances. From these results, it is found that the CRDM satisfies with the structural integrity and the drop performance for 2000 drop cycles.

Table 4 presents the endurance test results of stepping motor using a hunting motion of Table 1. This test is performed for 29,178 cycles per one time, and total 60 times are repeated. The error of the stepping motor due to the hunting motion is not found. This means that the stepping motor works reliably without the malfunction between the input and output signals.

Table 4 Endurance test results of stepping motor

No	Total Cycles	Error
1	29,178	0
2	29,178	0
. .	. .	. .
59	29,178	0
60	29,178	0

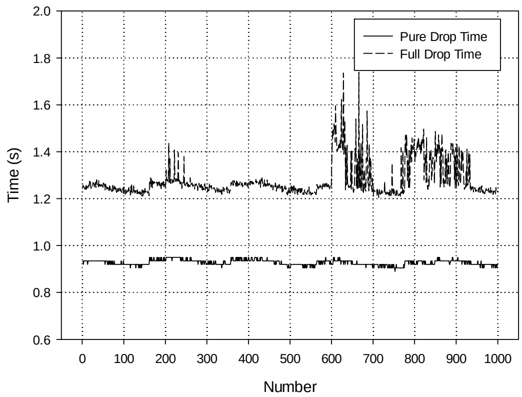

Fig. 6 Drop times during endurance test (10MW)

5. Conclusions

A performance and endurance tests of the top-mounted CRDM for the JRTR with the plate type fuel are performed using a prototype CRDM installed in the full scale full core test rig simulating the actual reactor's conditions. The results of the drop test show that the pure and full drop times of the CRDM meet the specified requirements of 1.5 and 3.0 seconds, respectively. However, because the initial delay times for the safety analysis was not acceptable with the AC-type electromagnet, we change into the DC-type magnet having a delay time lower than 0.1 second after the endurance test. The impact values at the instant of damping are measured as maximum 4g for the full drop of 650mm.

For the drop endurance test of 2000 times, the CRDM is satisfied with the structural integrity with good drop performance. From the results for the performance and endurance test of the stepping motor, it is found that the motor will work reliably without the malfunction between the input and output signals. Also any significant wears and damages for the CAR and CAR guide tube are not found after the performance and endurance tests.

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