Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

A New Concept of HANARO Irradiation Testing Method for Studying Dynamic Behavior of Nuclear Fuel

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1. Introduction

Since the nuclear fuel is a source of radioactive materials, the integrity of it must be maintained during operation of nuclear power plant. Therefore, the performance of newly developed fuel should be verified through various tests and evaluations for the application. Since the Fukushima accident, the accident tolerant fuel (ATF) has been actively developed worldwide. France and the United States are leading the technology of ATF. They are conducting the test at commercial nuclear power plant using lead test assembly (LTA) [1]. Recently, a provision was inserted into the EU taxonomy to use ATF [2]. In Korea, the ATF is being developed by the industry to apply in early 2030s [1]. The plan of ATF test using research reactor and commercial nuclear power plant was established.

The ATF is being developed with the goal of improving the performance under abnormal condition. However, the most tests focus on normal operation. Since the research reactor can conduct the test under various environments, it is relatively easy to check the performance of ATF. If the change of the power of nuclear power plant is implemented in the research reactor, the inherent safety of ATF at the accident condition can be confirmed. In addition, it can be also applied for the performance test of load-following operation for harmonization with renewable energy in the future. Therefore, we are developing a dynamic testing method, which has many differences with conventional static testing method. In this paper, the dynamic testing concept using HANARO is reviewed. We also present the results by evaluation and hydraulic test to verify the test method.

2. Dynamic test concept

We have conducted the test for various nuclear fuels. The test widely applied not only to commercial nuclear fuel [3] but also to fuel [4] and fission moly targets [5] for research reactor and fuel materials for GEN-IV nuclear system [6]. These tests were performed as the static method that the fuel power was determined by the operation environment of HANARO. Since the specimen temperature could not be controlled with the intention of tester, the application of test results was limited.

The neutron flux at HANARO is relatively higher than at the core of commercial nuclear power plant. This is verified by the measurement using self-powered neutron detectors (SPND) [7]. Therefore, if the position of the test fuel is controlled, the fission power of it can be adjusted. Halden reactor can conduct the test with the control of fuel power by moving fuel position and the utilization of He-3 [8]. Jules Horowitz Reactor (JHR), which is currently under construction, will prepare a facility called ADELINE and plan to use the method of inserting and withdrawing the test fuel into the core [9]. Although the operation environment of HANARO is different with above research reactors, we concluded that the dynamic test can be applied by changing the axial position of test rod.

Fig. 1 shows the concept of dynamic test at HANARO. We considered the OR irradiation hole as a test region because we have a lot of experience for fuel test in it. The neutron flux is the highest at the relatively central position in the axial direction of the core. The neutron flux is significantly lower at the outside of the core. Therefore, it is possible to control the fission power of fuel by axial moving. The axial movement of the test fuel rod is applied through the rotation of the screw rod. The rotation of it is transmitted from the electric power. The non-contact magnetic coupling is used to avoid the penetration of coolant. Since the test device can be electrically controlled by the control panel, we can track the movement of the test fuel rod.

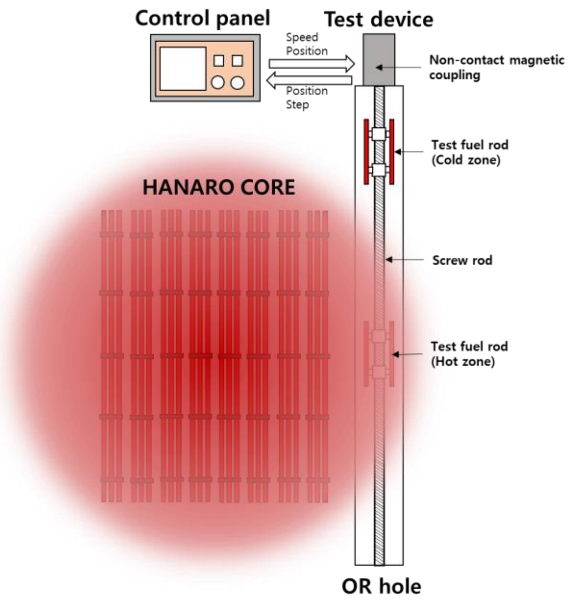


Fig. 1. The dynamic testing concept at HANARO

3. Evaluation and test results

3.1 Design of testing device

Fig. 2 shows a diagram of the test device. Three test rods can be accommodated in the device because structural safety has been verified in the previous tests. A total of eight magnets are installed both inner and outer sides in the circumferential direction. The moving power of electric motor is transmitted to the mechanically coupled outer magnet. Accordingly, the corresponding power is transmitted to the inner magnet by magnetic force. The screw rod mechanically coupled to the inner magnet rotates to move the fuel test rods axially. A rotation tracer is installed to track the slip of the non-contact magnetic coupling due to the hydraulic resistance.

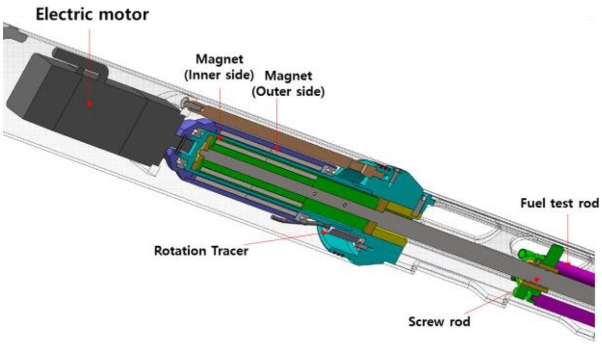
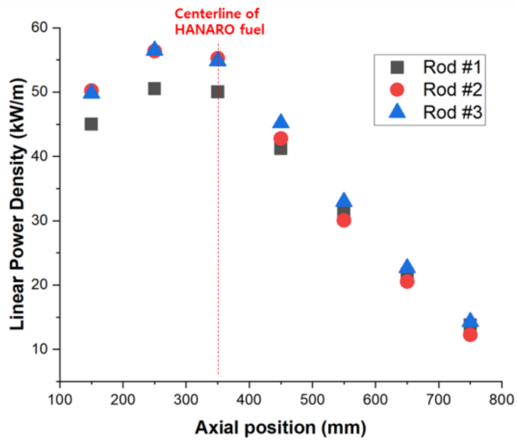
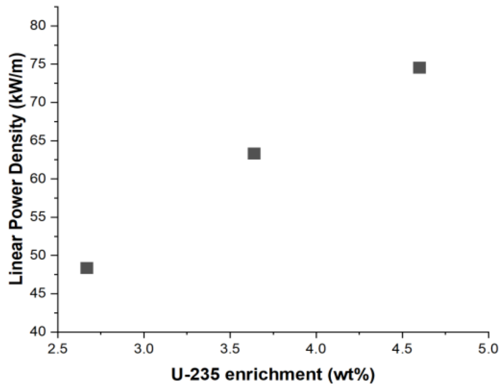


Fig. 2. A diagram of test device

Fig. 3 shows the evaluated results of the test rod power with the axial position and enrichment of U-235. MCNP6 [10] was used for evaluation and it was assumed that the control absorber rod (CAR) position is 450 mm in the equilibrium core in the middle of the cycle. Fig. 3(a) shows the linear power density of test fuel rods depending on the axial position. Fig. 3(b) shows the average linear power density of test fuel rods depending on the U-235 enrichment. We could clearly confirm the change of linear power density of fuel test rods by axial position. In particular, the effect of it is evident in the upper side than lower side of HANARO fuel centerline. This result is caused by CAR, which is inserted/withdrawn at the upper side of the HANARO core. As the enrichment value was increased, the linear power density was increased. Since there is a high possibility of increasing the enrichment of fuel due to the ATF application, the achievable linear power density is expected to increase. The average power density of commercial nuclear power plant is about 20 kW/m. Even if the local power picking is sufficiently considered, the linear power of test fuel rod is enough at HANARO. In case of previous test by Swedish researchers [11], the RAMP test was mainly performed less than 60 kW/m. Therefore, it is expected that the HANARO has the enough capability for the dynamic test of nuclear fuel in abnormal environment.



(a)



(b)

Fig. 3. The linear power density of test fuel rod with (a) Axial position and (b) U-235 enrichment

3.2 Hydraulic performance test

We fabricated the mockup test device to conduct the basic performance test. Since the coolant flows forcibly upward in the HANARO core, it should be observed whether the axial movement of the test rods is applied against the hydraulic resistance. For it, we machined some visual windows on the external tube of the device. The main concern is to check whether the power of motor is transmitted well through the non-contact magnetic coupling in the HANARO hydraulic environment. This is a key technology for dynamic testing method. In addition, we also evaluate the suitability of the entire system including control panel. Fig. 4 shows the pictures of mockup device and hydraulic test. Although there was some differences with the actual test device, it was confirmed that the axial movement of the dummy rods was conducted without any problems. Therefore, it could be expected that the dynamic test will be applied at HANARO OR irradiation hole by this dynamic testing concept.

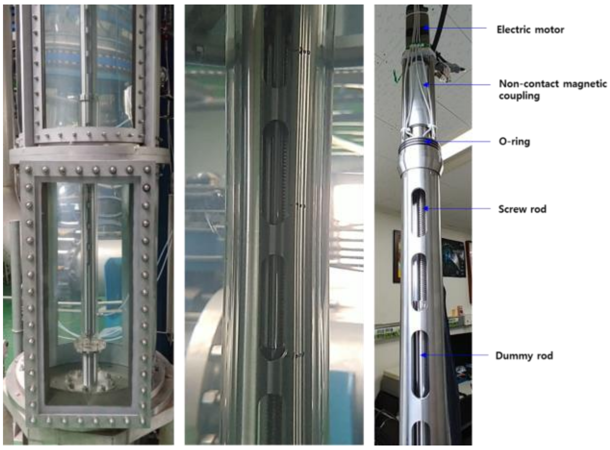


Fig. 4. The mockup device and hydraulic test

4. Conclusions

We proposed the new concept test system for dynamic testing of nuclear fuel. The basic testing method is to control the linear power density through the axial movement of the test fuel rod. If it is possible, we can apply the test under abnormal condition and load-following environment to observe the fuel performance. It was evaluated that the neutron flux in the HANARO OR hole is sufficiently achievable from the linear power analysis. We also verified a key technology, which is the driving mechanism by non-contact magnetic coupling, by the hydraulic test. Therefore, this test concept is sufficiently valid, and further studies are needed for the application.

ACKNOWLEDGEMENTS

This work was supported by the Korea government (MSIT) (1711078081).

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