Structural Integrity Test Results of Top Nozzle for i-SMR Fuel

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1. Introduction

An important requirement in i-SMR nuclear fuel design is flexible operation and the ability to operate without boron. Considering the above requirement, improved control rod is necessary to meet the core's subcriticality limitation. Accordingly, the number of control rod fingers has been increased from 24 to 28. To accommodate the 28 control rod fingers, four guided tubes have been added to the existing 17×17 array fuel assembly, resulting in a modified configuration that excludes four fuel rods. Additionally, the design of the top nozzle has also been revised, as shown in Fig 1[1].

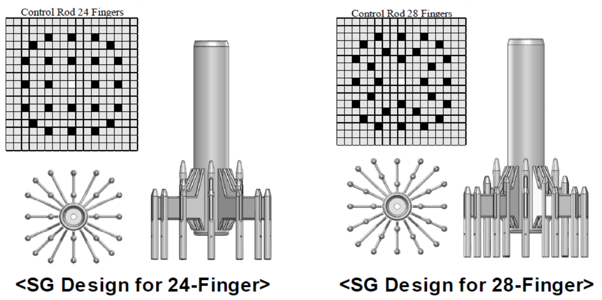


Fig. 1. Design of the fuel assembly array according to fingers

The top nozzle, positioned at the uppermost part of the fuel assembly components, is exposed to various loads during handling and transportation through handling tools and the clamps of the shipping cask. Additionally, it is located below the upper core plate (UCP) in the reactor, where it activates the hold-down spring to prevent disengagement from the core pin due to hydraulic loads during operation.

In this study, the design of the top nozzle was modified following the changes in the fuel assembly array. To verify the mechanical integrity of the modified top nozzle, experiments were conducted under various load conditions. After completing the tests for each load condition, the permanent deformation of the top nozzle adapter plate was measured to verify compliance with the design criteria.

2. Structural Integrity Test and Results

2.1. Structural Integrity Test

The adapter plate, which connects the top nozzle to the guide tube, functions to transmit and support the load acting on the top nozzle to the guide tube. To verify the mechanical integrity of the top nozzle, strain gages were attached to the adapter plate, a critical component, as shown in Fig. 2.

The test loads were conservatively calculated and determined to ensure the verification of the design criteria under each condition. A SHIMADZU universal testing machine (UTM) was used to apply the load by moving the crosshead vertically at a rate of 0.02 in/min. As shown in Fig. 3, the test setup for each condition was conducted by replacing the fixtures accordingly for each test condition.

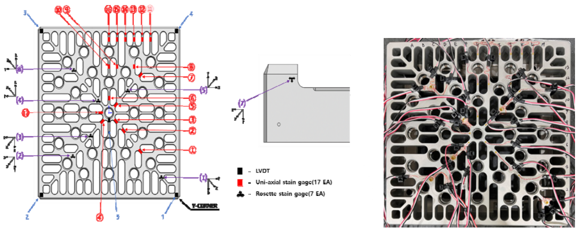


Fig. 2. Stain gage location

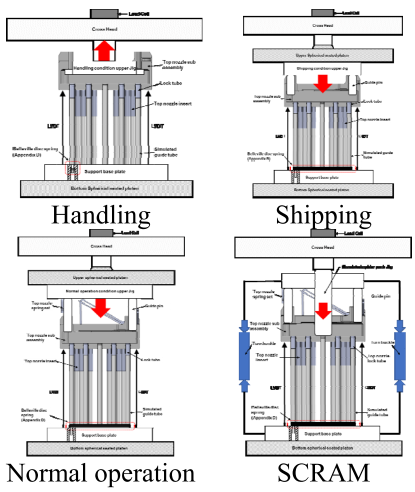
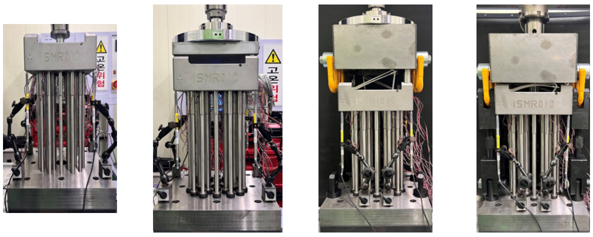


Fig. 3. Schematic of structural integrity test conditions

The signals from all sensors, including the load cell, LVDT, and strain gages, were collected using the SIEMENS SCADAS Mobile system. After completing each test condition, the flatness of the adapter plate was measured.

2.2. Test Results

The test configuration is illustrated in Fig. 4, while the test results, including strain measurements obtained from uni-axial and rosette strain gages under various loading conditions, are presented in Figs. 5 and 6. Furthermore, Table 2 provides the ratio of the calculated stress at the location of maximum strain measurement to the allowable stress determined in accordance with ASME BPVC Section III.



Handling Shipping Normal operation SCRAM

Fig. 4. Schematic of structural integrity test condition

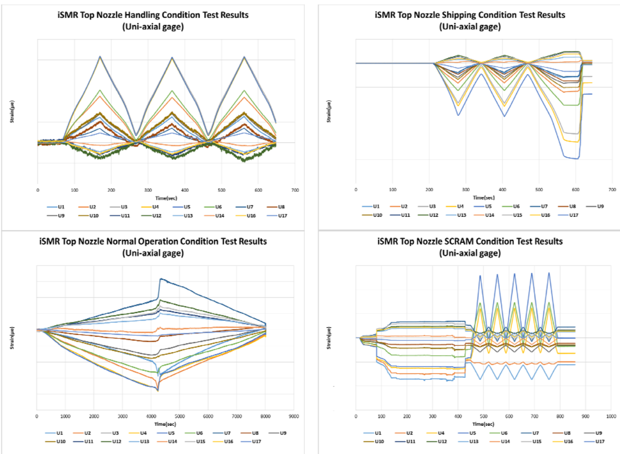


Fig. 5. Test results of uni-axial strain gage

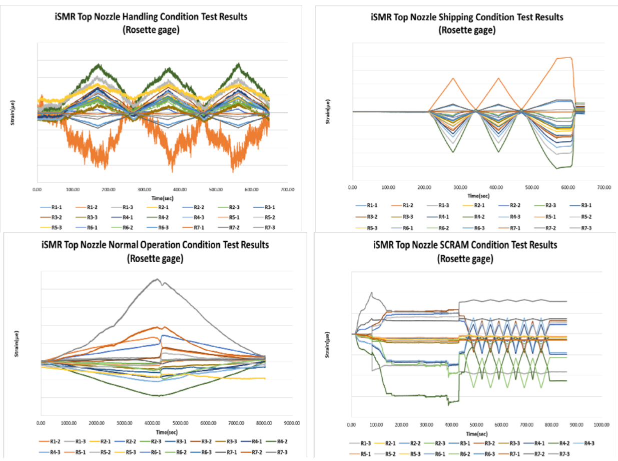


Fig. 6. Test results of rosette strain gage

Table 2. Maximum stress ratio $S_{test}/S_{allowable}$

Condition	Strain gage No.		$S_{test}/S_{allowable}$
Handling	Uni-axial	U3	0.39
	Rosette	R1-2	0.16
Shipping	Uni-axial	U5	0.52
	Rosette	R4-2	0.14
Normal operation	Uni-axial	U4	0.11
	Rosette	R7-3	0.13
SCRAM	Uni-axial	U5	0.32
	Rosette	R4-2	0.08

For the uni-axial strain gages, despite slight variations in location, the highest strain values were consistently recorded at U3, U4, and U5, which were positioned around the center of the adapter plate. In contrast, for the rosette gages, the location of the maximum strain varied depending on the test fixture setup, loading direction, and the installation of the hold-down spring.

However, under the Shipping and SCRAM(Safety Control Rod Axe Man) conditions, where the applied compressive load was concentrated on the central region of the adapter plate, the maximum strain was predominantly observed at the R4-2 gage positioned at the center. After completing the tests for each condition, the flatness of the adapter plate was measured to verify compliance with the design criteria. The results confirmed that the flatness remained within 0.005 in, satisfying the design criteria.

3. Conclusion

A mechanical integrity evaluation test was conducted to verify the design criteria of the top nozzle developed for i-SMR project. As a result, the strain at the critical regions of the adapter plate was measured, and the flatness was assessed, confirming compliance with the design criteria. In the future, structural analysis of the top nozzle will be performed for comparative verification with the test results.

ACKNOWLEDGEMENT

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REFERENCES

[1] Joo-Young Ryu, Kyoung-Hong Kim, Ba-Leum Kim, Dong-Geun Ha, Yoon-Ho Kim, "A Study on Dynamic Impact Analysis of Simplified Spacer Grid Designed for 24-finger and 28-finger Control Rods", Transactions of the Korean Nuclear Society Autumn Meeting, Oct. 24-25, 2024.