Introduction to Control Drum Driving System for Molten Salt Reactor

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1. Introduction

The molten salt reactor, MSR, is one of the 4th-generation reactors that use molten uranium-salt compounds as both fuel and coolant. Unlike light water reactors, MSR is operable at high temperatures and atmospheric pressure, featuring a simple structure and high thermal efficiency. Additionally, since the coolant and fuel are integrated, there is no risk of coolant loss accidents, ensuring inherent safety. For these reasons, MSR can be applied to reactors ranging from small to large and is being developed in various forms by different institutions. In this study, research on replacing combustion engines with reactors for transportation is ongoing as one of the studies. The drum type control rod driving system is being developed to ensure that the control rod and safety shutdown rod maintain consistent functionality and performance regardless of posture during operation.

2. Control rod diving system conceptual design

2.1. Design requirement

The control rod driving system is a system that performs safety functions, it should be designed based on redundancy, diversity and independence. When designing, it should have additional quantity(redundancy), operate on different principles(diversity) to prevent common error failures, be independent(independence) both mechanically and electrically. Reflecting these factors, control rods are arranged as shown in Fig. 1. The driving method consists of a system that uses a step motor and a system that utilizes the restoring force of the torsional spring ensuring operation even in the event of a loss of electric power. The scram time shall be within 2 seconds during the emergency shutdown, which is reflected in the selection of the step motor and design of the spring.

2.2 Control rod specification

Control rod consists of BeO as a reflector and B_4C as an absorber and is encased with 316H. The rotating inertia of the rod is 22.37 kg·m^2, and the torsional spring is designed to satisfy the scram time based on this value.

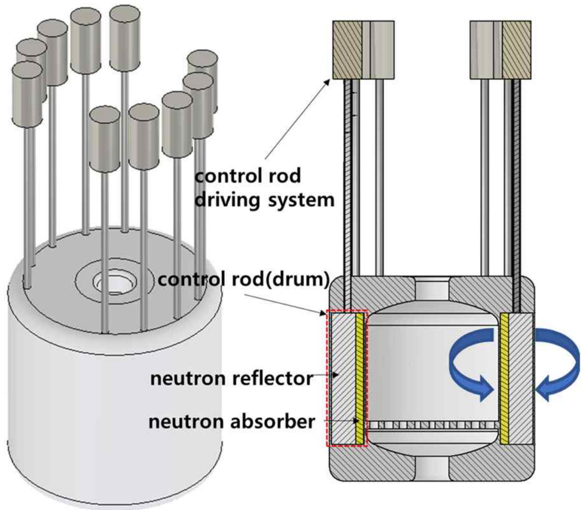


Fig. 1 Arrangement of control rod driving system

2.3 Torsional spring

The torsional spring should provide the restoring force that rotates the safety shutdown rod within 2 seconds in the event of step motor failure. The spring stiffness is determined under the assumption of free vibration of the safety shutdown rod using the following equations. The minimum stiffness required to satisfy scram time, 2s, is about 13.94 Nm/rad with a 10% of equivalent damping ratio.

$$f = \frac{1}{2\pi}\sqrt{\frac{k_\theta}{I}}\sqrt{1-\xi^2},$$

$$\text{scram time(2 seconds)} = \frac{1}{4f}$$

Although there are many forms of torsional spring, a spiral spring is selected considering factors such as component arrangement, the strength of spring material, and other considerations in the study. One of the spring designs is shown in Fig. 2.

For the uncertainty in damping, the spring is designed to have a larger stiffness than the design value. The reaction moment and stress are calculated under operating conditions with 180° rotation, and the moment is used as the design load for the design of other components.

$$k_\theta = E\frac{bt^3}{12L}$$

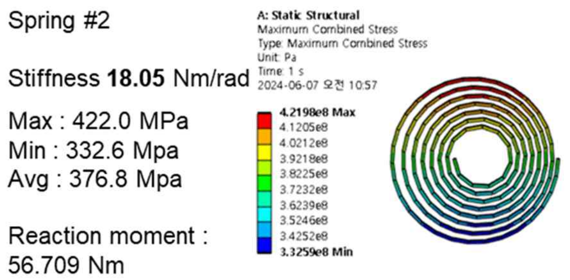
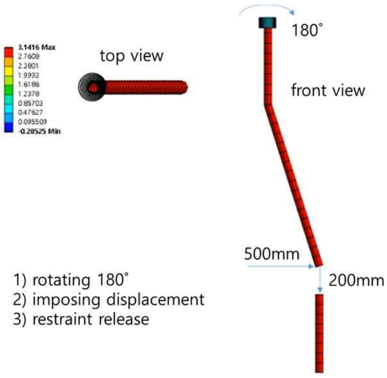


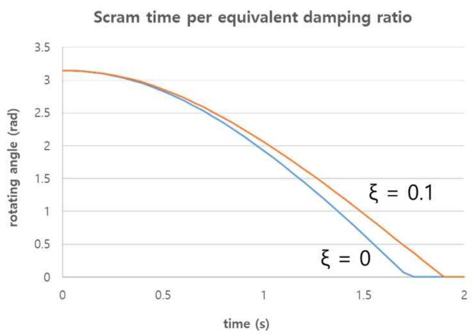
Fig. 2 Spiral spring design

2.4 Eccentric coupling

The MSR operates at high temperatures of 600℃, and the ambient temperature where the shutdown rod is located is controlled to maintain around 50℃ by the HVAC system. Therefore, different displacements due to unequal thermal expansion between the location of the control rod in reactor and the location of the upper driving system cause shaft misalignment. To compensate for this misalignment, a constant velocity (CV) joint that is widely used in vehicles is introduced. The operability of the scram with the CV joint is analyzed using ANSYS considering control rod inertia, spring stiffness, and kinematic degrees of freedom of the CV joint. The result is shown in Fig. 3.



(a) FEM model



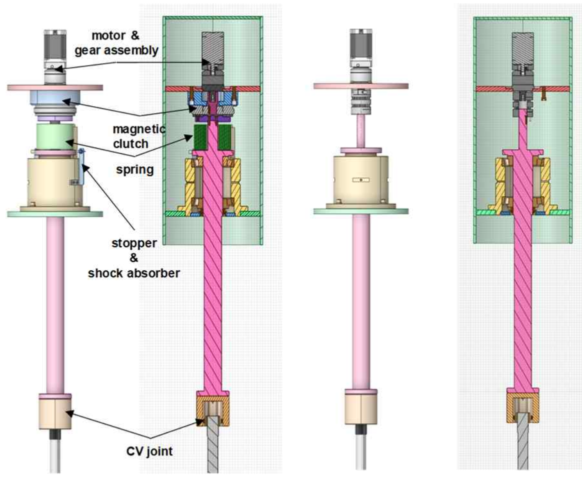
(b) scram simulation result

Fig. 3 Scram simulation with CV coupling

It can be confirmed that the scram time of 2 seconds is satisfied for both equivalent damping ratios of 0 and 0.1.

2.5 Component arrangement

For ensuring the spring works during motor failure, power transmission between the motor and shaft should be disconnected. To do that, a magnetic clutch is located between them. In the case of a power loss, the clutch is naturally turned off, and then the shutdown rod starts rotating by the spring force. The approximate component arrangement is depicted in Fig. 4.



(a) for safety shutdown (b) for power regulation

Fig. 4 Arrangement of control rod driving system

3. Conclusions

In this study, a conceptual design of the drum type MSR control rod driving system is conducted. The components are placed so as to satisfy the design requirement, and the operability is verified using simulation.

ACKNOWLEDEMENT

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REFERENCES

[1] MSR-SYS-REQ-FSS-001, “K-MSR 원자로용기 설계요건서”, KAERI
[2] MSR-SYS-DES-ETC-001, “해양용 MSR 계통배치개념”, “KAERI”
[3] MSR-SYS-REQ-SAS-001, “정지봉 구동계통 설계요건서”, KAERI
[4] MSR-SYS-REQ-SAS-002, “제어봉 구동계통 설계요건서”, KAERI