Reactivity Feedback Effects in DSFR

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1. Introduction

The reactivity feedback models are required to simulate ATWS (Anticipated Transient Without Scram) events in a nuclear reactor. Whereas the models for the Doppler and coolant is used in an accident analysis for an Light Water Reactor safety evaluation, additive reactivity feedbacks due to the change of the fuel temperature and core geometry have to be modeled in the safety evaluation for a Fast Reactor.

Additive models were implemented into the MARS-LMR code [1] and the ATWS events for the Demonstration Sodium-cooled Fast Reactor (DSFR) were analyzed using the code.

2. Reactivity Feedback Models

In this section three reactivity models used to simulate the ATWS events are described. The models include reactivity models for a fuel axial expansion, a core radial expansion, and a control rod insertion due to the core temperature change.

2.1 Reactivity due to the fuel axial expansion

A role of the axial expansion in the normal solid fuel pin geometry is to provide a prompt negative reactivity feed back at the start of a power transient. This mechanism is the principal prompt negative feedback available in a metal fueled fast reactor. The fuel axial expansion increases the core height as temperature rise and changes the reactivity of the system by increasing the neutron leakage. The result is a rapid negative feedback contribution from an increase in fuel temperature or a rapid positive feedback in response to a decrease in fuel temperature.

There are three models for the evaluation of the fuel axial reactivity coefficient such as free fuel expansion, force balance controlled expansion, and the model based on the fuel and clad temperature variation for the conservative analyses of a postulated accident condition. The third model was implemented into the MARS-LMR code. The amount of reactivity feedback, ρ^{ax}, is calculated by Eq. (1).

$$\rho^{ax} = \sum_J \left[\alpha^c \rho_J^c \cdot \nabla T_J^c + \alpha^f \rho_J^f \cdot \nabla T_J^f \right] \qquad (1)$$

where α and ρ is a linear expansion coefficient and an axial expansion reactivity coefficient. Superscripts '*c*' and '*f*' mean the clad and fuel, respectively. ∇T means the temperature difference between current time and initial time.

2.2 Reactivity due to the core radial expansion

The radial expansion of fuel due to increasing fuel temperature may increase fuel pin diameters slightly but will have relatively little effect on the radial expansion of the core. Bulk radial expansion of the core is governed primarily by the structure and, hence, the coolant temperatures, together with the influence of the radial restraint system.

The core assemblies are held by their nosepieces in the receptacles, and by the load pads near the top of the assemblies which are surrounded by a core restraint ring attached to the core barrel. However the intermediate load pads above the active core are not restrained by the core restraint ring. Thus, the core assemblies are free to bow by their temperature differences and metallurgical condition.

The reactivity feedback due to the core radial expansion, ρ^r, is calculated by Eq. (2) which considers above dictation.

$$\rho^r = \alpha^r \cdot ln\left(1 + W_{LP}\xi_{LP} + W_{GP}\xi_{GP}\right) \qquad (2)$$

where α^r is the radial expansion coefficient which is calculated assuming a uniform increase over the core radius. W is the geometrical weighting factor describing non-uniform expansion of the above core load pad and grid plate. ξ is the effective strain of load pad(LP) or plate(GP).

2.3 Reactivity due to the control rod driveline expansion

Thermal expansion of the drivelines due to a rise in core outlet temperature will cause the control rods to be inserted further into the core, providing a negative reactivity. On the other hand, if the drivelines are supported on the vessel head, and if the core is supported by vessel walls, then heating the vessel walls will either lower the core or raise the control rod drive supports, leading to a positive reactivity.

Final reactivity feedback due to the control rod driveline expansion, ρ^{crdl}, is calculated by summing the two expansion effects like as Eq. (3).

$$\rho^{crdl} = \alpha^{crdl} \cdot \left(\Delta Z_{cr} - \Delta Z_{vs}\right) \qquad (3)$$

where α^{crdl} is reactivity coefficient according to the control rod length. ΔZ_{cr} and ΔZ_{vs} are the length changes according to the time scale for the control rod driveline and vessel wall.

3. Calculation Results for ATWS

Three ATWS events of UTOP (Unprotected Transient of OverPower), ULOF (Unpro-tected Loss Of Flow), and

ULOHS (Unprotected Loss Of Heat Sink) for the DSFR were analyzed to test above 3 models.

3.1 UTOP

The UTOP event is initiated from the full power and postulates that a malfunction in the reactivity controller causes the withdrawal of all control rods and the reactor protection system fails to detect the event. As a result of the event, 0.3 $ is assumed to be inserted for 15 seconds.

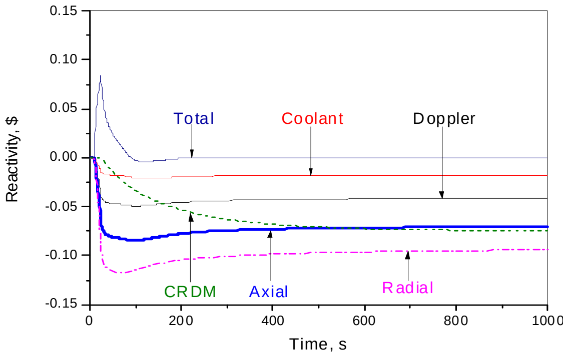

Fig. 1 Reactivity feedbacks for UTOP

In this event a Doppler feedback is usually dominant mechanism to limit the overpower event of the core. The metallic fueled core of the DSFR, however, induces a small Doppler feedback due to a hard neutron spectrum; instead, the DSFR core mostly depends on reactivity feedbacks from core radial expansion, fuel axial expansion, and control rod expansion to limit the peak power. The calculation results are consistent with the previous results for the KALIMER [2] system by the SSC-K code [3].

3.2 ULOHS

The accident is assumed to begin with a complete loss of the normal heat sink. A core protection system is also assumed not to be available.

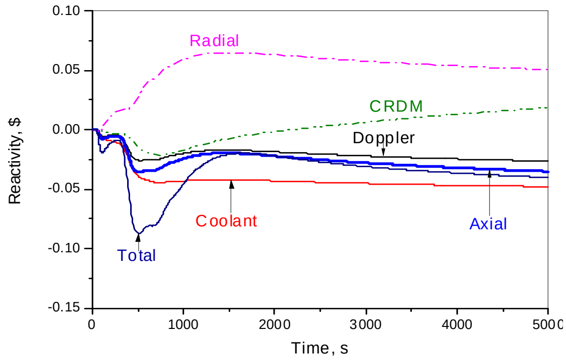

Fig. 2 Reactivity feedbacks for ULOHS

All reactivity feedback components are initially negative due to the rise of the primary coolant temperature. Owing to the negative reactivity, the power goes down and the fuel temperature is decreased. The radial reactivity is positive as time goes on. The Doppler, fuel axial expansion, and coolant reactivities keep negative values. A slope of total reactivity after about 1,500 sec is always negative to be enough to shutdown the reactor.

3.3 ULOF

The ULOF event is initiated by all primary pump trips followed by a coast-down. It is assumed that the RPS fails to detect the event.

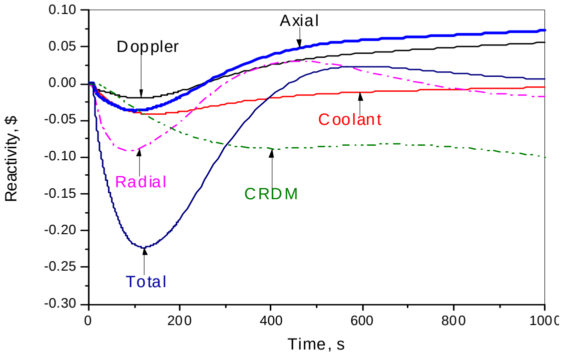

Fig. 3 Reactivity feedbacks for ULOF

The Doppler and axial feedback turns into a positive response after 200 sec but, the initial large amount of negative reactivity is enough to shutdown the reactor. After 500 sec, the slope of total reactivity keeps negative value due to the negative feedback of the radial, control rod driveline, and coolant. The results qualitatively coincide with the theoretical reactivity feedback solution.

5. Conclusion

Three reactivity feedback components were embodied into the MARS-LMR code and three typical ATWS events were analyzed using the code. All calculation results are consistent with the previous results by the other code and qualitatively coincide with the theoretical reactivity feedback solution.

ACKNOWLEDGMENTS

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