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Investigation of Reactivity Feedback Mechanism of Axial and Radial Expansion Effect of Metal-Fueled Sodium-Cooled Fast Reactor

Seung-Hwan Seong [a*], Chi-Woong Choi, Tae-Kyung Jeong and Gi-Seok Ha
[a]*Korea Atomic Energy Research Institute, 111, Daedeokdaero, 989beon-gil, Yuseong, Daejeon, 305-353*
**Corresponding author: shseong@kaeri.re.kr*

1. Introduction

A PGSFR (prototype Gen-IV sodium-cooled fast reactor) is under development at KAERI. The PGSFR uses metal fuels in core and the characteristics of metal fuels are different from those of the conventional ceramic fuel. Especially, the inherent reactivity feedback models for the reactor dynamics are very different. The major inherent reactivity feedback models for a ceramic fuel used in a conventional light water reactor are Doppler feedback and moderator feedback. The metal fuel has these two reactivity feedback mechanisms previously mentioned. In addition, the metal fuel has two more reactivity feedback models related to the thermal expansion phenomena of the metal fuel. Since the metal fuel has a good capability to expand according to the temperature changes of the core, two more feedback mechanisms exist. These additional two feedback mechanism are important to the inherent safety of metal fuel and can make metal-fueled SFR safer than oxide-fueled SFR. These phenomena have already been applied to safety analysis on design extended condition. In this study, the effect of these characteristics on power control capability was examined through a simple load change operation. [1]

The axial expansion mechanism is induced from the change of the fuel temperature according to the change of the power level of PGSFR. When the power increases, the fuel temperatures in the metal fuel will increase and then the reactivity will decrease due to the axial elongation of the metal fuel.

The radial expansion mechanism is induced from the coolant temperature in the core through similar process. When the power increases, the coolant temperature will increase and the core will radially increase. Finally, the reactivity of the core will decrease.

These reactivity feedback mechanisms can improve the stability and safety of the PGSFR compared to the conventional light water reactors because the more negative reactivity during an inadvertent power transient event will be inherently inserted into the core by the expansion effect discussed above.

By a simple power transient simulation, the stability and safety of the reactor core was examined in this study.

2. Power Transient Event

For investigating the stability of metal-fueled PGSFR, a power transient event was simulated. In this event, the control rod movement was not permitted because looking at only the reactivity feedback effect of the PGSFR core was intended in the simulation result. The reason is as follows: If the control rod moves to adopt the power transient event, the reactivity feedback effect is not independently shown because the reactivity worth of the control rod is much higher than the reactivity change originated the various feedback mechanisms.

The simulation scenario is as follows. Also, all cases were performed without control rod movement and the power of the reactor was controlled by only the reactivity feedback mechanism. The reactor power could be followed by the change of BOP power. Since the detailed BOP system is not required in this study, the BOP power was simulated as the heat transfer rate through the steam generator. The flow rate of the feedwater was controlled to match the heat transfer rate through the steam generator with BOP power. For this simulation, the constant steam pressure and temperature as well as the constant pressure of the feedwater were assumed. Initially the reactor and BOP maintained at the steady condition. At 1500 sec of simulation time, the BOP power was suddenly dropped to 90% from 100% power and then the BOP power was kept till 3500 sec. Then, the BOP power was decreased to 50% with ramp rate of 5%/min and maintained the BOP power of 50% until 7000 sec and, finally, the BOP power was recovered up to 100%. During simulation, the flow rates of PHTS and IHTS followed the BOP power, which is an operational strategy of PGSFR.

3. Simulation Result

To evaluate the expansion effect, 2 cases were simulated with the same scenario by using MMS-LMR code developed at KAERI. [2][3]

The first simulation was to analyze the change of the reactor power according to the change of BOP power without the reactivity feedback model of the axial and radial expansion of the core during the power transient event. That is to say, the core had only two reactivity feedback mechanism of Doppler and coolant temperature.

The second was to analyze the change of the reactor power with Doppler and coolant temperature effect and the reactivity feedback mechanism induced from the axial expansion of fuel and the radial expansion of the reactor of PGSFR.

Comparing two simulation results, the effect of the reactivity feedback from the axial and radial expansion effect was investigated.

Fig. 1 shows the reactor power change by the change of the BOP power in this simulation. As shown in Fig. 1, the reactor power well followed the BOP power in both simulations without the movement of control rod. The results of power transient are the same each other. Therefore, there is no significant effect of thermal expansion effect on power control of PGSFR.

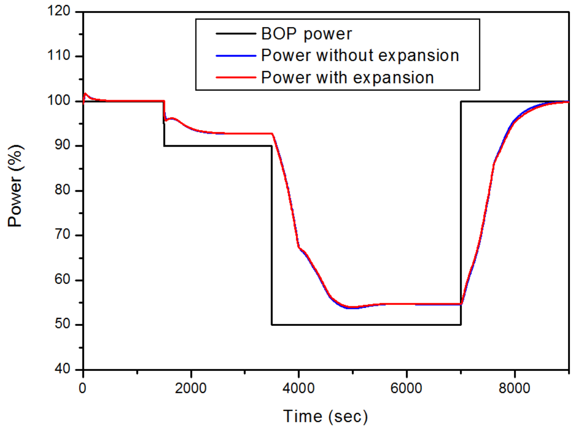

Fig. 1 Reactor Power according to BOP power.

Fig. 2 shows the flow rates of PHTS and IHTS according to the power level of PGSFR. Unlike the design feature of a conventional pressurized water reactor, the flow rates of the PHTS and IHTS were changed according the reactor power level as the operational strategy of PGSFR.

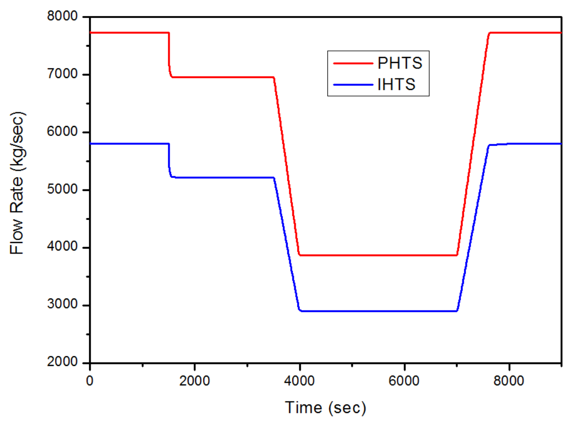

Fig. 2 Flow rates of PHTS and IHTS

Fig. 3 shows the reactivity change of the simulation without the feedback mechanism of the axial and radial expansion. As shown in the figure, the reactivity feedback mechanism of Doppler and coolant temperature worked well in the PGSFR although the feedback mechanism induced from the axial and radial expansion according the power transient was not considered.

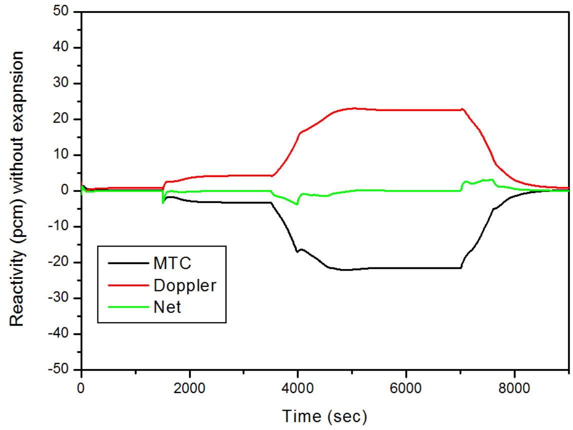

Fig. 3 Reactivity change without expansion effect

Fig. 4 shows the reactivity change of the simulation with the feedback mechanism of the axial and radial expansion as well as Doppler and coolant temperature. As shown in the figure, all the reactivity feedback mechanisms worked well in the PGSFR. However, the effect of radial expansion feedback (negative reactivity), which comes from increased coolant temperature, is offset by the axial expansion effect (positive reactivity) which comes from decreased fuel temperature according to reactor power decrease.

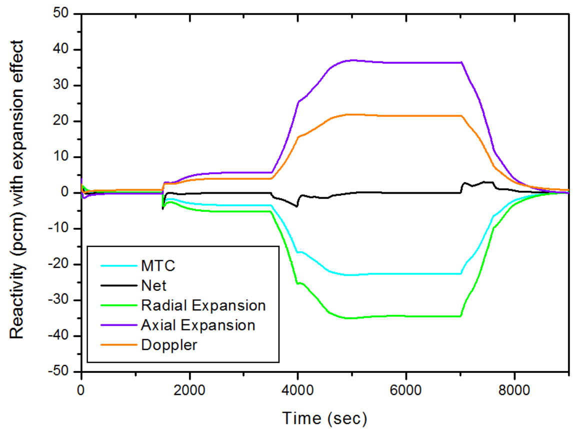

Fig. 4 Reactivity change with expansion effect

Fig. 5 shows the change of the coolant temperature in PHTS. The temperature was slightly increased during the power transient event. The temperature of hot pool increased beyond trip setpoint of high temperature of hot pool (571℃). In this simulation, the trip function was ignored to investigate only the reactivity effect.

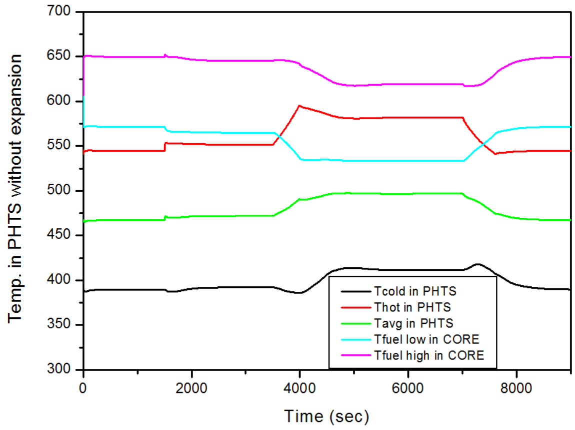

Fig. 5 Temperature of PTHS without expansion effect

Fig. 6 shows the change of the coolant temperature in PHTS. The temperature was nearly kept nominal values during the power transient event. The temperature of hot pool kept below trip setpoint of high temperature of hot pool. This result shows the stability and safety of the PGSFR core including the reactivity feedback mechanism of the axial and radial expansion of the metal fuel.

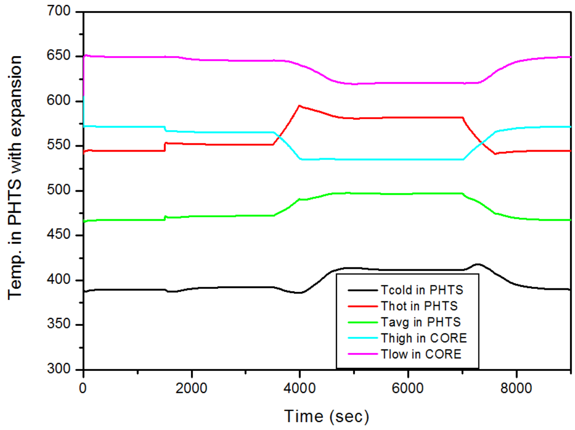

Fig. 6 Temperature of PTHS with expansion effect

From the simulation results, the reactivity feedback mechanism of the axial and radial expansion of the metal fuel could be offset during power operation of the PGSFR.

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