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An Application of The LSWCR(lower shifted worth control rod) for The Power Maneuvering for Pressurized Water Reactor

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Abstract

In this research, Two lower shifted worth control rods (LSWCR) are suggested to mitigate problems related to variation of axial power distribution during power maneuvering. Then, two experiments are performed. The one experiment is in condition that the LSWCR1 is fixed at bottom of the core and the LSWCR2 is moved, and the other experiment is in condition that LSWCR2 is fixed at half of the core, and the LSWCR1 is moved. From the application results, it is shown that the insertion of LSWCR at 100% power equilibrium state, can produce the required reactivity to return to full power, and a boron concentration change is minimized. It seems possible that a combinative use of LSWCR1 and LSWCR2 controls AO within the target AO band

I. Introduction

The nuclear power plant has limited operation flexibility, compared with other power plants, due to special consideration of core safety. Therefore, in the present operation of electric grid in Korea, the nuclear power is used as only base load means, and change in electric power generation to follow load change is performed by other electric power sources, such as fossil power plant. However, as the share of the nuclear power in an electric power generation increases, there is a growing needs for nuclear power plants to be able to follow load changes on a utility's power system, therefore the load follow capability and operation of nuclear power plants becomes more important.

In a nuclear power plant, the reactor power change is cause by changes in reactivity. Two primary mechanisms for reactivity changes are control rods and soluble boron. Cylindrical control rodlets of neutron absorbing material are assembled into clusters and manipulated as groups(banks) of clusters. Soluble boron control involves the use of a neutron absorber in the form of boric acid, dissolved in the coolant to compensate for slow reactivity change. A moderator temperature control is auxiliary means. To produce favorable steam generation characteristics, PWRs operate at a programmed average coolant temperature. However, it is desirable at times to allow coolant temperature to deviate from its programmed value and to utilize the reactivity feedback effects to produce a desired power change.

During a power change operation of a nuclear power plant, the reactor core is in a transient state induced by transient effects of xenon, which is one of the fission product and is a very strong absorber of thermal neutrons. The reactivity change using above mechanisms makes variation of xenon concentration and axial distribution. A change in xenon axial distribution causes xenon oscillation, which makes reactor be able to reach uncontrollable state or trip. Therefore, preventing a xenon oscillation is important. And to prevent a xenon oscillation, maintaining the axial power distribution within prescribed range is required, during power maneuvering.

In this study, axial variable strength control rods are suggested to mitigate variation of axial power distribution during power maneuvering, and a new power maneuvering strategy with suggested control rods is developed. In addition, minimizing boron concentration change is considered on the new power maneuvering strategy.

II. Background

Power distributions are represented by a variable called axial offset(AO) or axial shape index(ASI).

$$AO(=ASI)=\frac{P_T-P_B}{P_T+P_B}$$

$$\Delta I=P_T-P_B$$

where,

ΔI : power difference between top and bottom half core

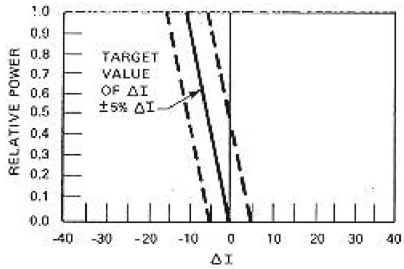
P_T : power in top of core

P_B : power in bottom of core

This is simply the normalized difference between the power in the top half of the core and the power in the bottom half of the core. The top and bottom core power indications needed to calculate AO are obtained from top and bottom nuclear detectors that are located outside the reactor vessel.

The basic idea behind the Westinghouse power distribution control philosophy, called constant axial offset control (CAOC), is to keep the AO within a control band about a reference AO value(target ASI) that corresponds to the most stable axial power distribution possible for existing core conditions, that is, the power shape existing at full power with equilibrium xenon and no control rods in the core.

Then, the AO(ASI) target band is determined as follows: This target band must be sufficiently narrow such that the benefits of lowered peaking factors can be obtained, yet also must be sufficiently broad to allow the plant operator to make power change easily. The target power difference band and corresponding AO band around a typical target are chosen to meet these dual objectives. Typically the selected target boundaries are ±5%, as shown in Fig.1.



$$\Delta I_{target} - 5\% < \Delta I < \Delta I_{target} + 5\%$$

Fig.1 The target band of ΔI

AO is calculated by dividing ΔI by relative power. Therefore, target boundary is ±5% at 100% power, but target bands broaden as the relative power decrease, as shown in Fig.2.

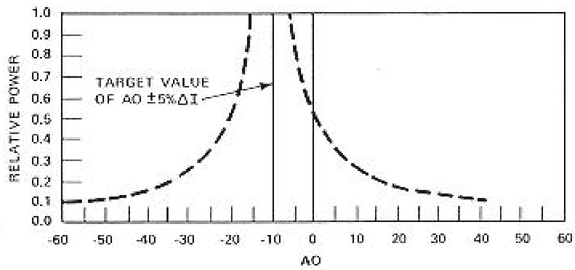


Fig.2 The target band of AO

And AO(ASI) target band according to power variation is shown in Fig.3.

In the CAOC operation, a power reduction without control rod insertion always tends to move the AO in the positive direction because of the negative moderator temperature coefficient. Therefore, a proper amount of full length control rod group insertion tends to move the AO back to the original target AO(negative direction). Thus, the full length rods are used for two purposes in this status-to absorb the reactivity insertion associated with the power reduction, and to maintain the AO at its original value. The prime factor in determining the degree of full length rod insertion should be AO control rather than reactivity control. In some case, the full length rod insertion necessary for CAOC is not enough to control the reactivity change associated with the power reduction. The balance of the reactivity change is then controlled through changes in the moderator boron concentration. Also, the degree of full length rod insertion during part power operation is not large enough to produce the reactivity required to return th full power, therefore boron dilution is necessary.

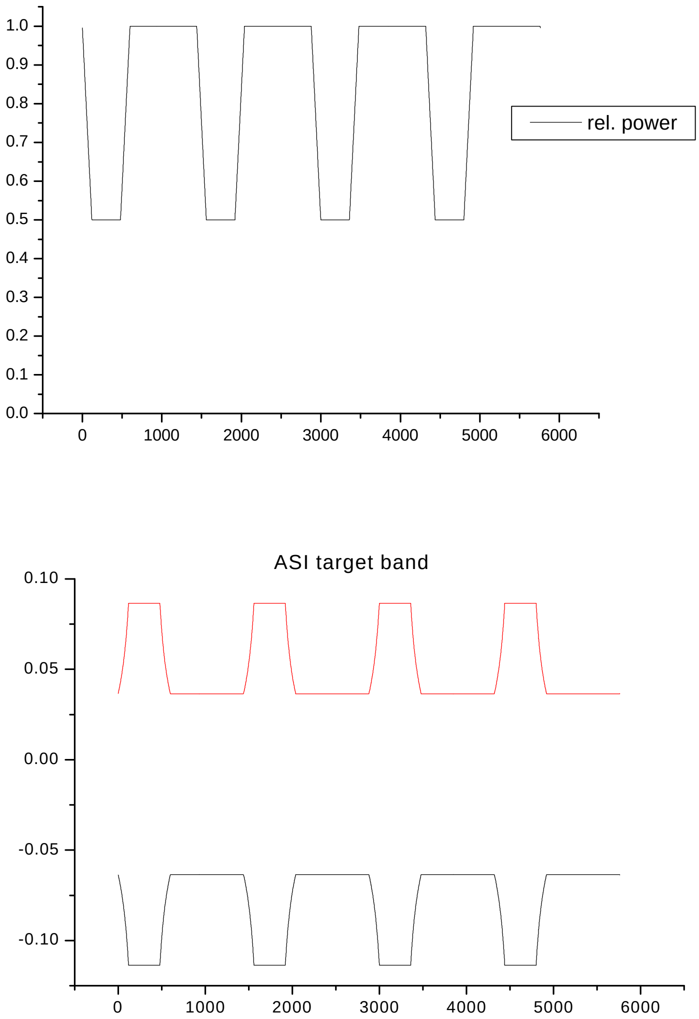


Fig.3 AO(ASI) target band according to power variation

III. Development and application of variable strength control rods for power maneuvering

A motion of control rods in a reactor core involves variation of axial power distribution. As shown in Fig.4, AO moves linearly when control rod moves. And when control rod stops, AO shows oscillation result from xenon oscillation. In the top half of the core, a control rod insertion moves AO to the negative direction, and withdrawal moves AO to the positive direction. In the bottom half of the core, *vice versa*.

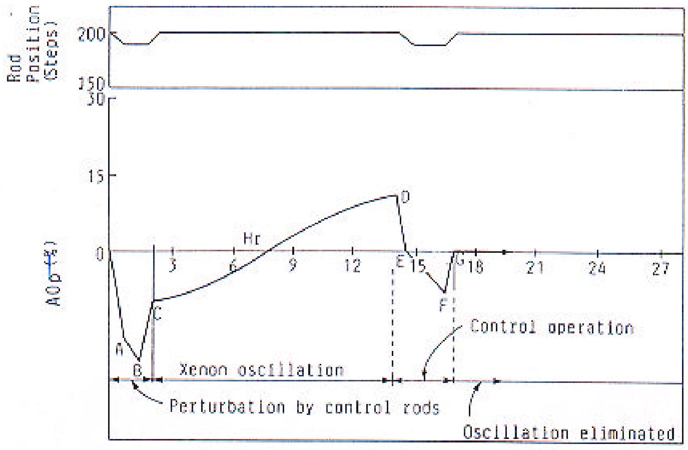


Fig.4 AO characteristics according to control rod motion

However, the AO variation must be kept in the AO target band, mentioned above. This characteristic makes it difficult to maneuver reactor power using control rods, and limits control rod motion. In this research, therefore, axial variable strength control rods are suggested to mitigate problems related to variation of axial power distribution during power maneuvering. The main purpose of axial variable strength control rods is lifting up the AO, and this rods produce reactivity change, of course, like normal control rods.

III.1 Lower shifted worth control rods (LSWCR)

Two lower shifted worth control rods (LSWCR) are suggested. Firstly, the LSWCR1 is fully inserted at initial state. AO approaches the upper AO boundary at fully inserted with LSWCR2. The purpose of LSWCR1 are lifting up AO at initial state, and control AO to the negative direction, and produce required reactivity instead of boron dilution. The initial worth shape of rod is shown in Fig.5.

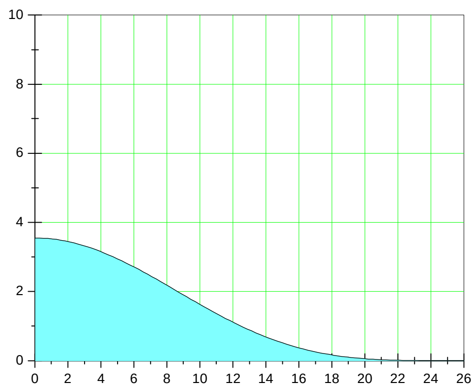


Fig.5 Initial worth shape of LSWCR1

Secondly, the LSWCR2 is inserted to the half of core at initial state. The purpose of LSWCR2 are control AO to the positive direction, and produce required reactivity in stead of boron dilution like LSWCR1. The initial worth shape of LSWCR2 is shown in Fig.6.

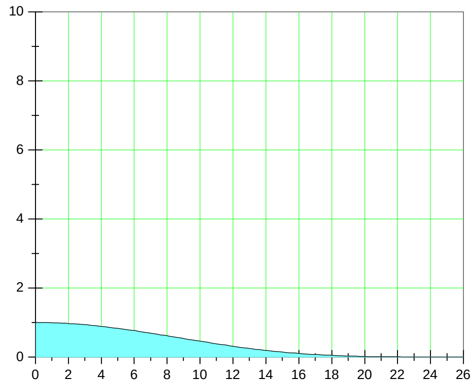


Fig.6 Initial worth shape of LSWCR2

III.2 Regulating rods (LSWCR5~3)

The others are regulating rods, and these rods have the same function with existing control rods. These rods are fully withdrawn at initial state, and the main purpose of these rods is reactivity change. In addition, during insertion, AO change to the positive direction after passing the center of core because of lower shifted worth shape. The initial worth shape of regulating rods is shown in Fig.7.

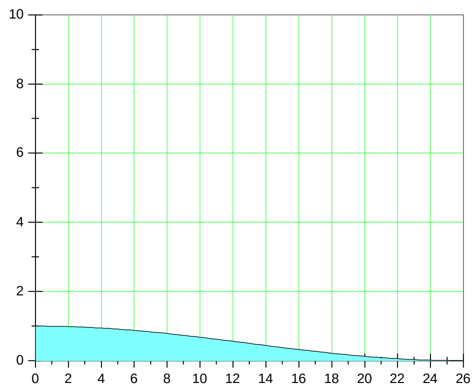


Fig.7 Initial worth shape of regulating rods

III.3 Application of LSWCRs

In respect of axial power distribution, a power variation with boron concentration change involves axial power distribution change. For instance, a power reduction with boration always tend to move the AO in the positive direction because of the negative moderator temperature coefficient. Therefore, utilization of boron concentration change for reactivity compensation makes it difficult to solve AO related problems with variable strength rods during power maneuvering. For that reason, minimization of boron concentration change is necessary. However, the degree of control rod insertion during part power operation is not large enough to produce the reactivity required to return to full power, and boron dilution is necessary. Therefore, the other means that performs above boron's role, instead of boron concentration change, is required.

In this work, hence, the lower shifted worth control rods(LSWCR1, LSWCR2) are inserted at initial state 100% power equilibrium. The ONED94 code is selected for application plant. The LSWCR1 is fully inserted and the LSWCR2 is half inserted, then equilibrium boron concentration is obtained by boron search. This initial state is shown in Fig.8.

The operation strategy for LSWCR1, and LSWCR2, in this application, is as follows:

- moving condition of LSWCR1
  ① required rod speed > 0
  ② all regulating rods are withdrawn
  when ①&②, LSWCR1 moves with the rod speed.

  ③ required rod speed < 0
  ④ steps of LSWCR1 > 0
  when ③&④ LSWCR1 moves first with the rod speed.

- moving condition of LSWCR2
  ① required rod speed > 0
  ② all regulating rods are withdrawn
  when ①&②, LSWCR2 moves with the rod speed.

  ③ required rod speed < 0
  ④ steps of LSWCR2 > 100 (half of core)
  when ③&④ LSWCR2 moves first with the rod speed.

This operation strategy will be continuously developed to satisfy following objective. The final objective of this operation strategy is that after ond-day cycle, all regulating rods are withdrawn, LSWCR1 is bottom of core, and LSWCR2 is half of core.

Then, two experiments are performed. The one experiment is in condition that the LSWCR1 is fixed at bottom of the core and the LSWCR2 is moved according to the above strategy. The other experiment is in condition that LSWCR2 is fixed at half of the core and the LSWCR1 is moved according to the above strategy. The execution results is shown in Fig.9 and Fig.10.

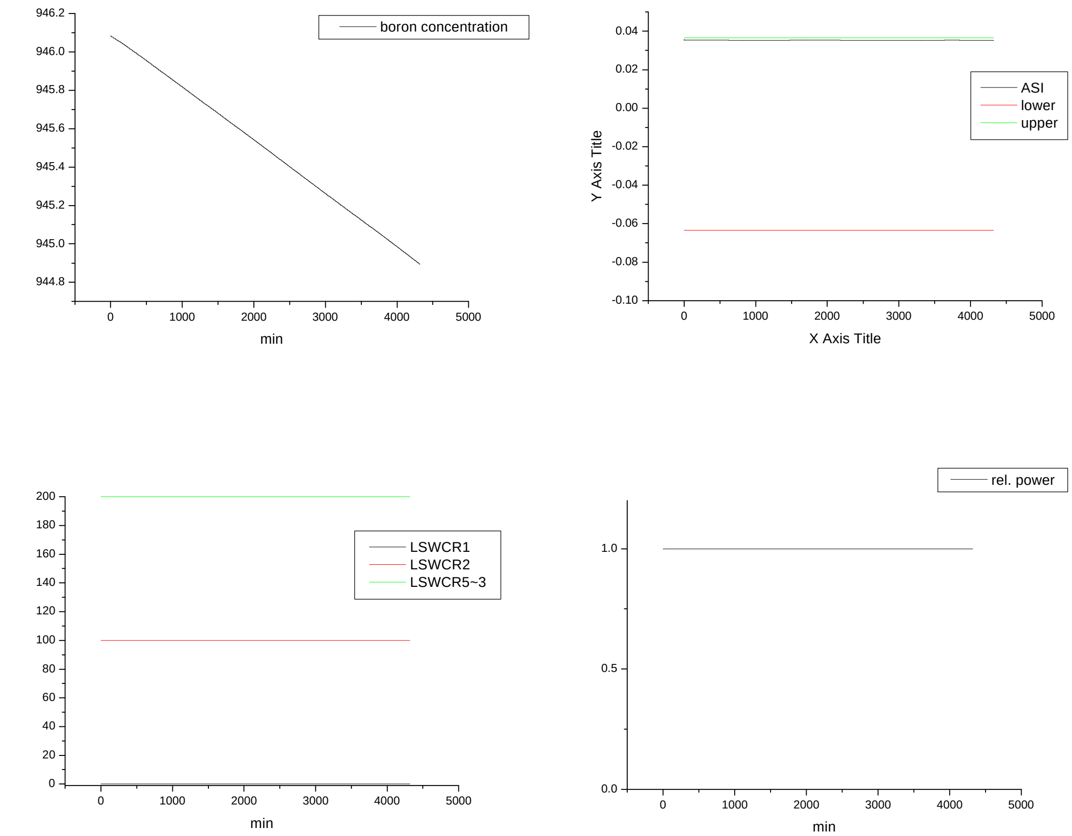
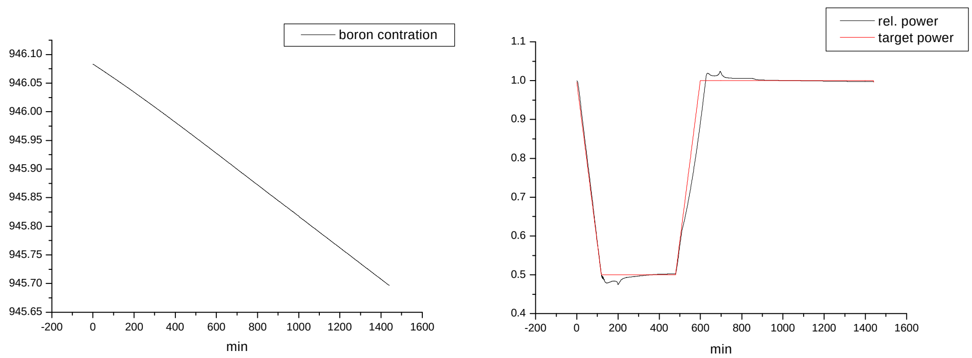


Fig.8 Initial state of application



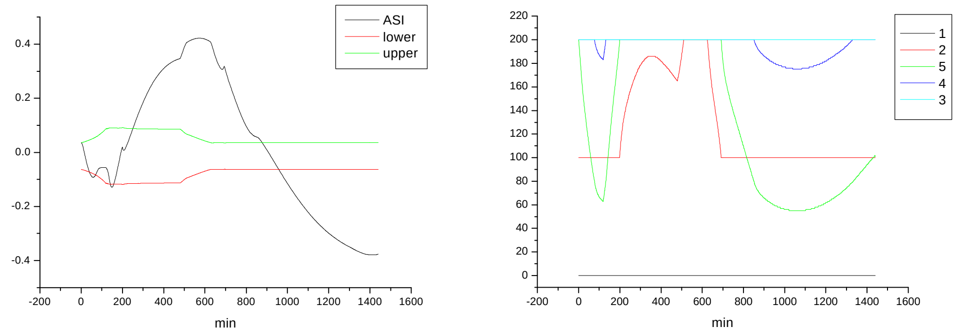


Fig.9 The execution result(moving LSWCR2 only)

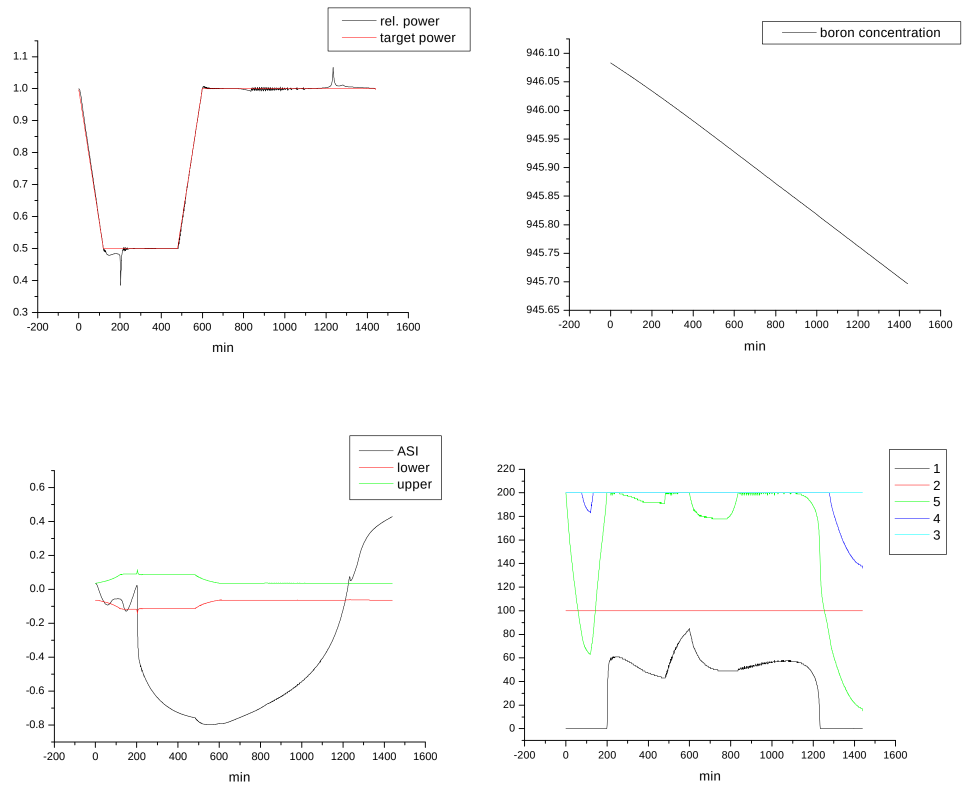


Fig.10 The execution result(moving LSWCR1 only)

From the first result, it is shown that the LSWCR2 has a such characteristic that move the AO to the positive direction when this rod moves to positive direction. The other result shows that the LSWCR1 has such characteristics that life up the AO at the bottom of the core, and move the AO to the negative direction when the rod moves to the positive direction. Therefore, it seems that the combinative use of these two rods(LSWCR1, LSWCR2) makes it possible to control the AO within the target band during power maneuvering, from the both results. In addition, the minimization of boron concentration change is possible.

IV. Conclusion

In this research, axial variable strength control rods are suggested to mitigate problems related to variation of axial power distribution during power maneuvering. The main purpose of axial variable strength control rods is lifting up the AO, and this rods produce reactivity change, of course, like normal control rods. Two lower shifted worth control rods (LSWCR) are suggested. The first is a rod named LSWCR1, and the purpose of LSWCR1 are lifting up AO at initial state, and control AO to the negative direction, and produce required reactivity instead of boron dilution. The other is a rod named LSWCR2, and the purpose of LSWCR2 are control AO to the positive direction, and produce required reactivity in stead of boron dilution like LSWCR1.

Then, two experiments are performed. The ONED94 code is selected for application plant, and the LSWCR1 is fully inserted and the LSWCR2 is half inserted at initial state, and initial equilibrium boron concentration is obtained by boron search. The one experiment is in condition that the LSWCR1 is fixed at bottom of the core and the LSWCR2 is moved according to the above strategy. The other experiment is in condition that LSWCR2 is fixed at half of the core, and the LSWCR1 is moved according to the above strategy.

From the application results, it is shown that the insertion of LSWCR at 100% power equilibrium state, can produce the required reactivity to return to full power, and a boron concentration change is minimized. It seems possible that a combinative use of LSWCR1 and LSWCR2 controls AO within the target AO band

References

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