ANAYSIS OF XENON SPATIAL OSCILLATION IN A CANDU-6 REACTOR WITH DUPIC FUEL

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ABSTRACT

The characteristics of the xenon spatial oscillation of a CANDU-6 reactor with DUPIC fuel has been assessed for three important harmonic perturbations, such as top-to-bottom, side-to-side, and front-to-back oscillations. For each oscillation, the instability index of the DUPIC fuel core has been calculated and compared with that of a natural uranium core. Parametric calculations have also been performed to analyze the effect of the power level and axial power shape on the xenon oscillation. This study has shown that the instability of the xenon oscillation increases for the DUPIC fuel core compared with the natural uranium core. However, this study has also shown that the current reactivity device system suppresses the xenon oscillation completely for both the natural uranium and the DUPIC fuel cores.

1. INTRODUCTION

The xenon spatial oscillation is an important factor for operation of a power reactor. In general, the susceptibility to xenon oscillation arises from the out-of-phase interaction between the positive and negative reactivity feedbacks due to the destruction of ^{135}Xe by neutron capture and its formation by the decay of the fission product ^{135}I. Especially, the large power reactor such as a Canada deuterium uranium (CANDU) reactor is more susceptible to the spatial oscillation. The extent to which a reactor is susceptible to the spatial xenon oscillations depends on the core dimensions, the power level, the shape of the unperturbed flux distribution. The typical CANDU-6 reactor core (Fig.1), which is about 628 cm in diameter and 594.4 cm in axial length, is more susceptible to the radial oscillation than the axial oscillation. When the DUPIC fuel is loaded in a

CANDU-6 reactor, the power and flux distributions are different from those of a natural uranium core (the power distribution is more flattened), which could affect the xenon spatial instability and controllability. In this study, the xenon spatial oscillation of the CANDU-6 reactor with the DUPIC fuel has been analyzed through a comparative study of the reactor with the standard 37-element natural uranium fuel. In addition, the spatial and bulk controllability of the zone controller units (ZCUs) has been assessed for the xenon spatial oscillation.

2. XENON OSCILLATION

The susceptibility of the core to the spatial xenon oscillation can be analyzed from the interactions between the functions describing the xenon concentration behavior and the neutron diffusion equations describing the flux distribution. In this study, the space-time diffusion calculations are used for the instability prediction. For the calculation, the group constants and xenon properties are obtained from WIMS-AECL[1] and the space-time diffusion calculations are performed by RFSP[2] , which is used for the CANDU core design and analysis.

2.1 Initiation of Oscillation

In this study, three higher harmonic modes are considered for the analysis of the xenon spatial oscillation characteristics: the top-to-bottom, the side-to-side and the front-to-back oscillations. These three harmonic modes are typical oscillations considered in the CANDU core physics design. The oscillations are initiated by withdrawing and subsequently reinserting the adjuster rods (ADJs) to perturb the steady-state flux and xenon distribution. For the top-to-bottom oscillation, all ADJs (Fig. 1) are withdrawn by 50% and reinserted to induce an oscillation. The side-to-side oscillation can be induced by fully withdrawing the ADJ numbers 5, 6, 7, 12, 13, 14, 19, 20, and 21 simultaneously. The axial oscillation is induced by fully withdrawing the ADJ numbers 1, 2, 3, 4, 5, 6, and 7 together.

2.2 Measure of Oscillation

The oscillation characteristics can be represented by power tilts, which are defined as:

$$\text{Top-to-bottom tilt (\%)} = \frac{(P_{1,8} + P_{3,10} + P_{6,13}) - (P_{2,9} + P_{5,12} + P_{7,14})}{\sum_{i=1}^{14} P_i} \times 100, \tag{3}$$

$$\text{Side-to-side tilt (\%)} = \frac{(P_{1,8} + P_{2,9}) - (P_{6,13} + P_{7,14})}{\sum_{i=1}^{14} P_i} \times 100, \tag{4}$$

$$\text{Front-to-back tilt (\%)} = \frac{\sum_{i=1}^{7} P_i - \sum_{i=8}^{14} P_i}{\sum_{i=1}^{14} P_i} \times 100, \tag{5}$$

where, P_i is the power of the zone i.

For the top-to-bottom xenon oscillation, shown in Fig. 2, the maximum tilt of the DUPIC core is 45.4%, and the oscillation time is about 170 hrs, while the oscillation time of the natural uranium core is 120 hrs with the maximum tilt of 44.5%. For the side-to-side xenon oscillation shown in Fig. 3, it can be seen that the oscillation also continues for 170 hrs with the maximum tilt of 37% at 13 hrs after the perturbation. The oscillatory behavior is more distinctive for the front-to-back tilt as shown in Fig. 4. For the DUPIC fuel core, the duration time is about 60 hrs with the maximum tilt of 13%. However, there is only a minor axial oscillation for natural uranium fuel core, which is mostly due to the axial power shape that strongly couples the front and rear zone powers.

3. PARAMETRIC ANALYSIS OF XENON OSCILLATION

The xenon oscillation characteristics have been analyzed through the parametric studies on the damping factor, the threshold power, the effect of axial power shape, and the controllability of ZCU system. The damping factor is a measurement of the rate of decay of the oscillation, which is defined as the ratio of the oscillation amplitude over an oscillation period. The threshold power is defined as a specific power level over which the xenon oscillation occurs.

3.1. Damping Factor

The xenon oscillation induced by a perturbation follows an exponential-sinusoidal behavior, which can be expressed by

$$P(t) = A_0 + P_0 e^{\xi t} \sin(\frac{2\pi}{T} t + t_0) \quad (6)$$

where P(t) is the oscillating variable at time t, A_0 is the steady-state value of the oscillating variable, P_0 is the amplitude of the envelope of the oscillating term at time zero, T is the period of the oscillation, t_0 is the phase shift, and ξ is the damping factor. The damping factors have been determined for the xenon oscillations using least square fits of the calculated oscillating variables in Eq. (6).

For the DUPIC fuel core, the damping factor for the top-to-bottom oscillation is $-1.767 \times 10^{-2}\ \mathrm{hr}^{-1}$, which is 45% smaller in magnitude than that of the natural uranium core. The damping factors of the side-to-side and front-to-back oscillations are decreased by 37% and 79%, respectively, compared to those of the natural uranium fuel core. All damping factors of the DUPIC fuel core are smaller in magnitude compared to those of natural uranium fuel core, which means that the instability of the xenon oscillation for the DUPIC fuel core is increased compared with that of natural uranium core. Table 1 compares the damping factors and other parameters for the natural uranium and the DUPIC fuel cores.

3.2. Threshold Power

The threshold power of the xenon oscillation was investigated for various power levels. The calculations were performed for the top-to-bottom oscillation, which is the most pronounced oscillation type for a CANDU reactor. As shown in Fig. 5, the threshold power of the DUPIC fuel core is about 10% of full power, while it is 20% to 40% [3] of full power for the natural uranium core, which is again an increase of the instability of the xenon oscillation for the DUPIC fuel core.

3.3. Effect of Power Flattening to Axial Oscillation

For the DUPIC fuel core, the 2-bundle shift fueling scheme is adopted for the on-power refueling of fresh fuels, which gives a more axial power flattening compared to the natural uranium core, where the 8-bundle shift fueling scheme is used. In order to assess the effect of the power flattening to the axial xenon oscillation, the xenon oscillation calculations were performed using different fueling schemes. As shown in Fig. 6, the xenon oscillation decreases rapidly with increasing number of fuel bundles shifted and the xenon oscillation is negligible for the 6-bundle and 8-bundle shift refueling schemes.

3.4. ZCU Controllability

The CANDU-6 reactor has 14 ZCUs in order to maintain the reference power distribution. The controllability of the current ZCU system was assessed against the power perturbation associated with the xenon spatial oscillation. The xenon oscillations of the DUPIC fuel core with and without spatial control are compared in Figs. 7 to 9 for the top-to-bottom, side-to-side and axial oscillation, respectively. The simulations have clearly shown that the ZCU system immediately compensates for zone power variations associated with the xenon oscillations.

4. CONCLUSION

The xenon spatial oscillation characteristics for the CANDU-6 reactor loaded with the DUPIC fuel has been assessed. This study has shown that the xenon spatial oscillation of the DUPIC fuel core is larger than that of the natural uranium core. However, the xenon oscillations are self-damped for both the natural uranium and DUPIC fuel cores. It is also shown that the threshold power of the DUPIC fuel core for the xenon oscillation is smaller than that of the natural uranium core and that the front-to-back xenon oscillation can be reduced by increasing the number of fuel bundle shifted per refueling operation. Even though the xenon oscillation increases, the current ZCU system maintains the damping capability of the xenon oscillation for the DUPIC fuel core.

ACKNOWLEDGEMENTS

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3. "Design Manual : CANDU 6 Generating Station Physics Design Manual, Wolsong NPP 2 3 4", 86-03310-DM-000 Rev. 1, Atomic Energy of Canada Limited, 1995.

Table 1 Damping factors for xenon oscillation

Oscillation Type	Damping factor (hr^{-1})	
	DUPIC core	Natural uranium core
Top-to-Bottom	-1.767×10^{-2}	-3.244×10^{-2}
Side-to-Side	-1.594×10^{-2}	-2.635×10^{-2}
Front-to-Back	-2.517×10^{-2}	-1.198×10^{-1}

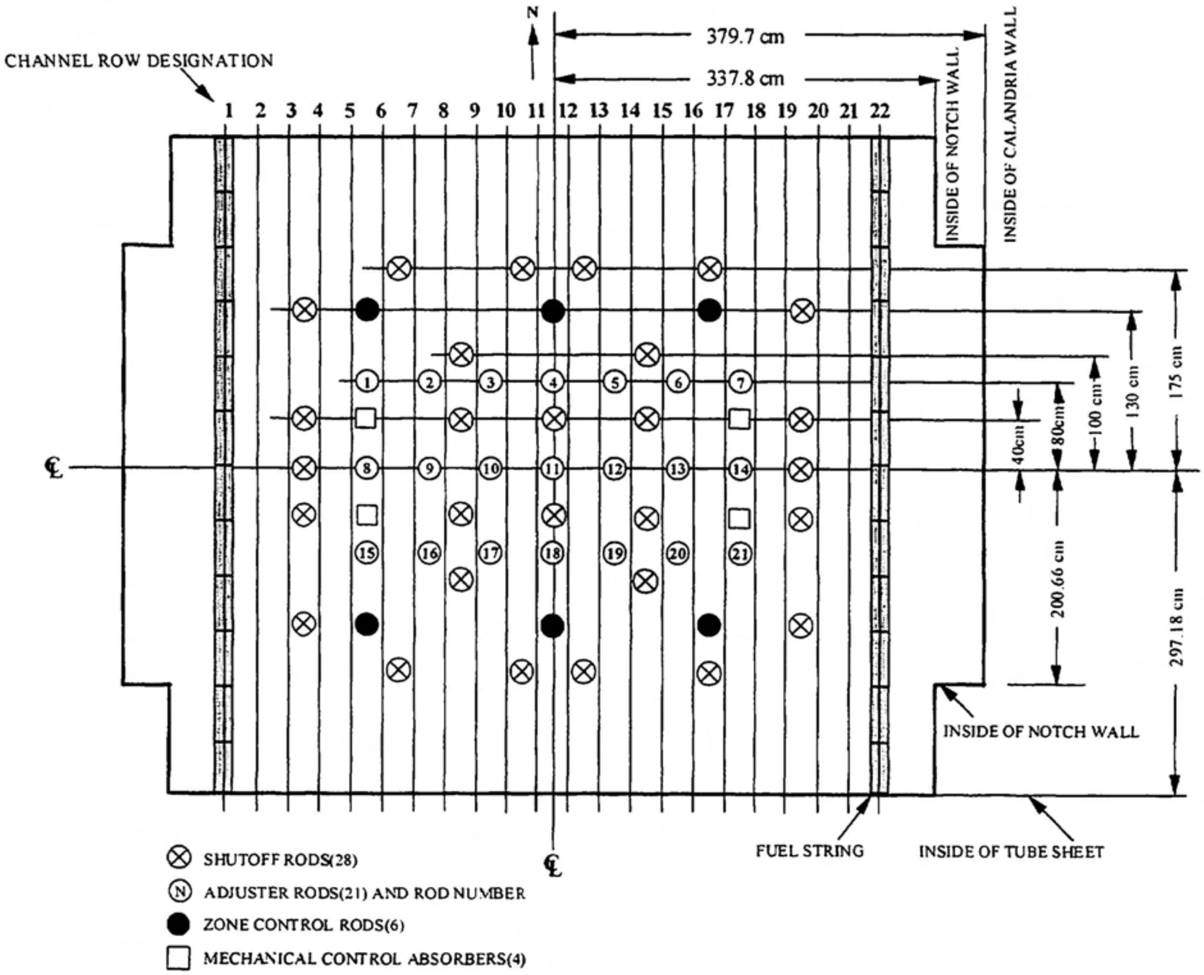

Fig.1 Plan View of CANDU-6 Reactor Showing Reactivity Devices

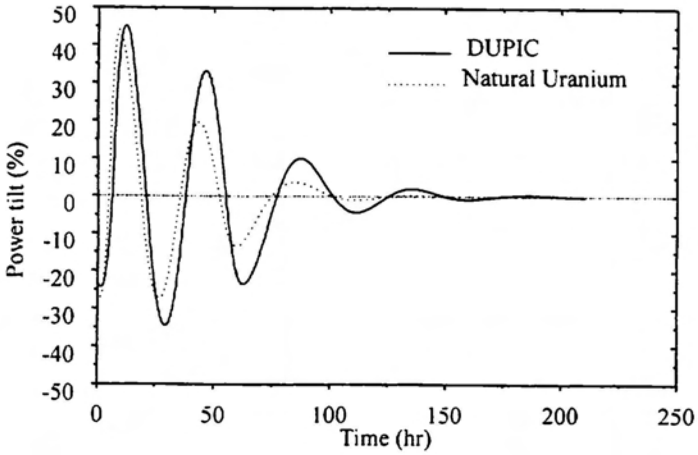

Fig. 2 Comparison of Top-to-Bottom Oscillation

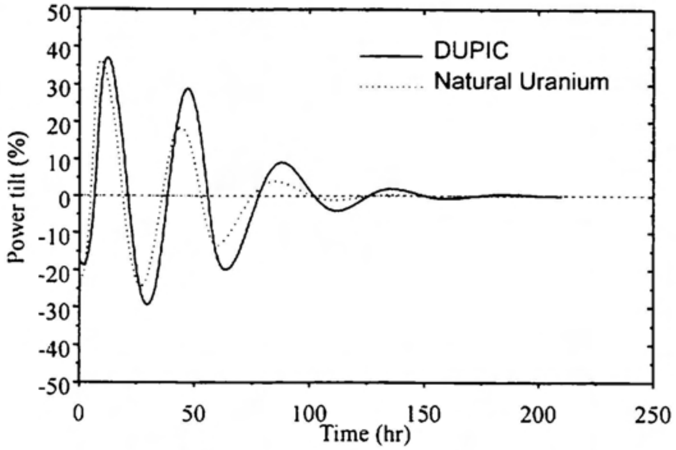

Fig. 3 Comparison of Side-to-Side Oscillation

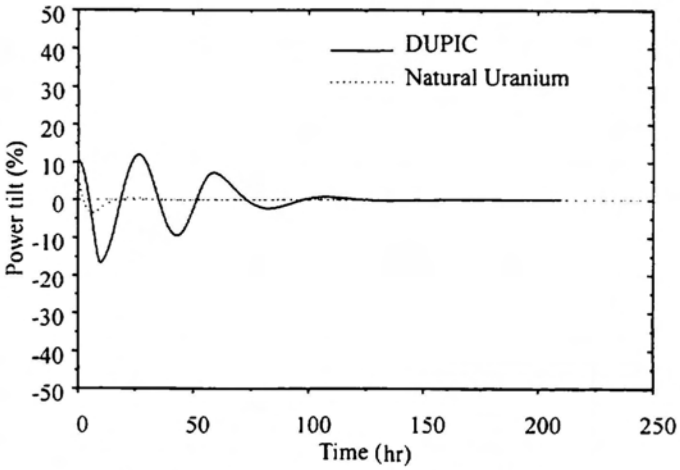

Fig. 4 Comparison of Front-to-Back Oscillation

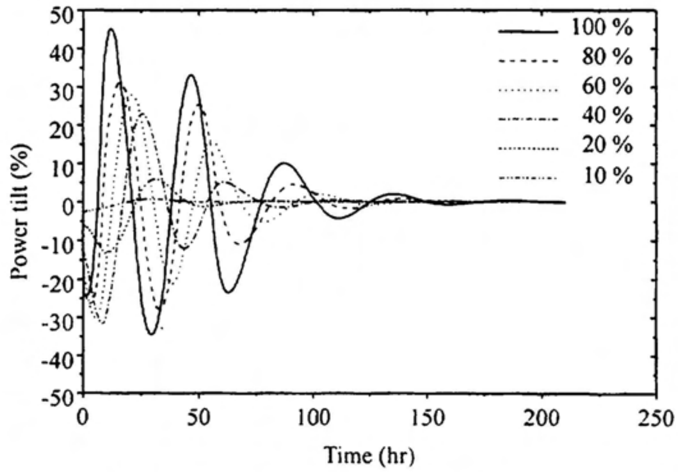

Fig. 5 Comparison of Top-to-Bottom Oscillation with Different Power Levels (DUPIC Core)

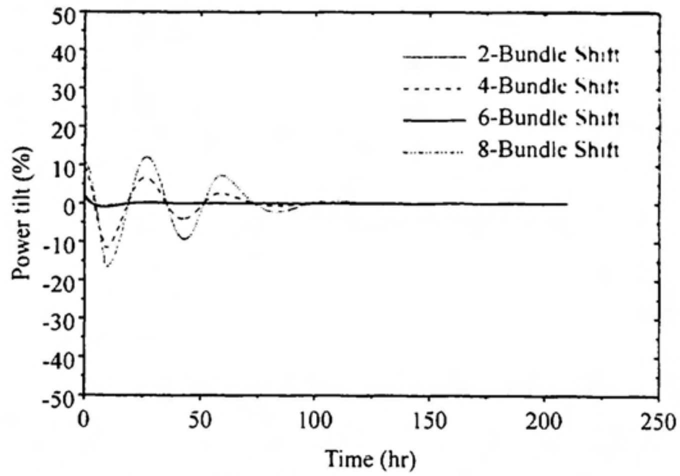

Fig. 6 Comparison of Front-to-Back Oscillation with Different Refueling Schemes (DUPIC Core)

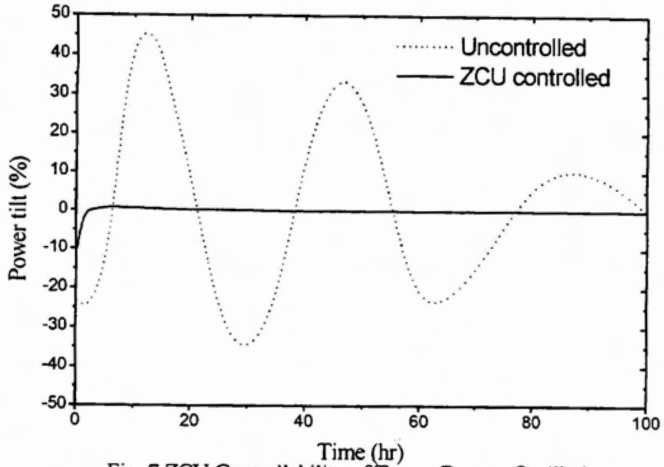

Fig. 7 ZCU Controllability of Top-to-Bottom Oscillation
(DUPIC Core)

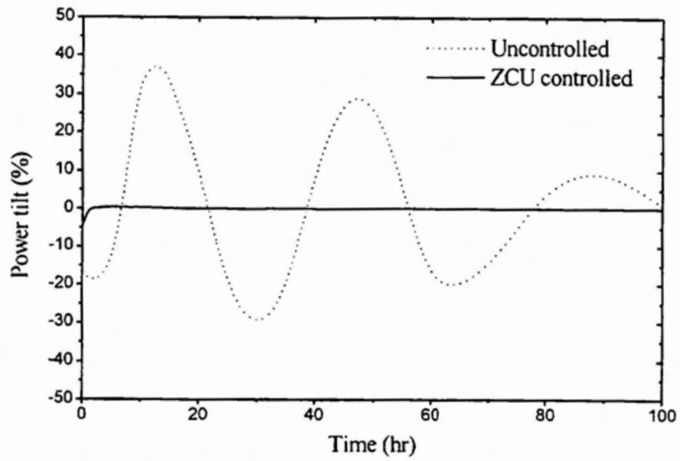

Fig. 8 ZCU Controllability of Side-to-Side Oscillation
(DUPIC Core)

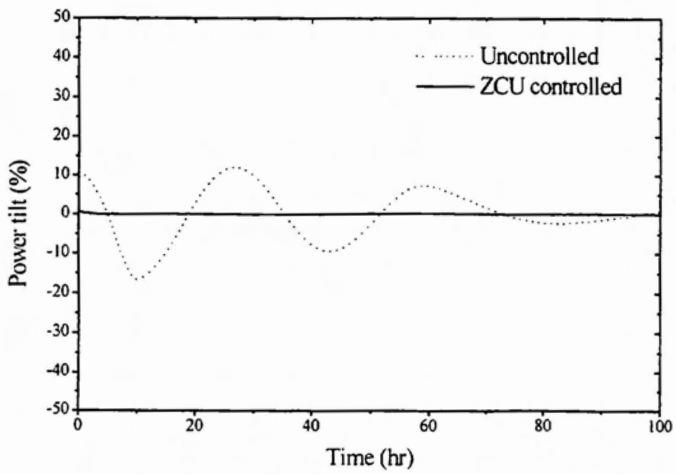

Fig. 9 ZCU Controllability of Front-to-Back Oscillation
(DUPIC Core)