Preliminary Analysis of the Bundle-Duct Interaction for the fuel of SFR

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1. Introduction

BDI (Bundle-Duct Interaction) occurs in the fuel of SFR (Sodium-cooled Fast Reactor) due to the radial expansion and bowing of a fuel pin bundle. Under the BDI condition, excess cladding strain and hot spots would occur [1]. Therefore, BDI, which is the dominant deformation mechanisms in a fuel pin bundle, should be considered to evaluate the FBR fuel integrity.

The analysis codes such as ETOILE [2] and BMBOO [3], have been developed to evaluate the BDI behavior. The bundle duct interaction model is also being developed for SFR in Korea [4]. This model is based on ANSYS [5].

In this paper, the fuel pin configuration model for the BDI calculation was established. The preliminary analysis of the bundle-duct interaction was performed to evaluate the fuel design concept.

2. Methods and Results

In this section, the fuel pin configuration model for the BDI calculation, and the bundle-duct interaction analysis are described.

2.1 Fuel Pin Configuration Model

In a fuel assembly with the wire-wrap, the spacing of fuel pins is maintained by the wire-wrap.

Figure 1 shows the fuel pin configuration for the BDI calculation. As shown in figure 1, each pin is wrapped with 19 turns of wire in a helical pattern.

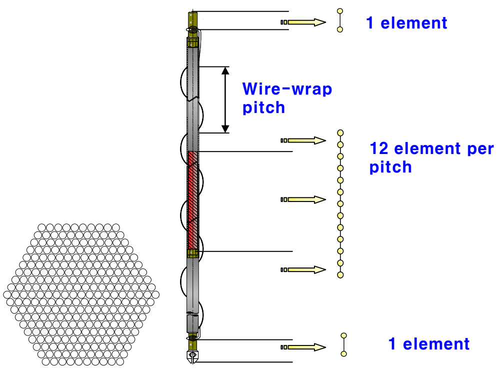

Fig. 1. Fuel pin configuration for the BDI calculation

The fuel pin was divided into a combination of a basic element. The basic element was composed of one PIPE 20 element.

The bottom end of each fuel pin was rigidly supported. From lower end plug to the wire-wrap start point, it was considered that the number of the finite element was 1.

From wire-wrap start point to the core start point, the number of possible contact points was 12 per one pitch of the wire-wrap. From the core start point to the plenum, the number of possible contact points was 12 per one pitch of the wire-wrap, too. The wire-wrap was considered separately at each nodal point of the beam element.

For the upper end plug, it was considered that the number of the finite element was 1.

The LINK8 element in ANSYS was used for the expansion and oval deformation of a fuel.

The CONTACT52 element in ANSYS was used for the fuel-to-fuel or the fuel-to-duct contact points.

2.2 Bundle-Duct Interaction Analysis

To evaluate the BDI for the fuel of SFR, a complicated computation should be carried out on a fuel subassembly containing 271 pins.

However, a lot of computing time is needed to analyze the BDI in the ANSYS calculation, because numbers of nodes are about 99,552 for the 271 pins.

In this paper, in order to check the parameters which affect the BDI, the bundle duct interaction of 19 rods was preliminary analyzed.

The basic input of this model is the fuel assembly geometry, the material properties, the temperature and the neutron flux.

The parameters should be considered to evaluate the BDI are 1) the fuel spec (such as the wire-wrap pitch length, the wire-wrap diameter, the cladding thickness, the fuel rod diameter), 2) the fuel assembly configuration (such as the number of fuel rods, the displacement of the wrapper tube walls, the wire-wrap configuration), 3) operating conditions (the power gradient, temperature, flux), 4) material properties (the thermal expansion rate, the creep and swelling rate).

The key geometric parameters for the BDI analysis are shown in Table 1.

Table I: Key parameter

Outer diameter of cladding [mm]	8.5
Inner diameter of cladding [mm]	7.3
Outer diameter of spiral wire [mm]	1.4
Wrapper pitch of spiral wire [mm]	203
Number of fuel pins	19
Number of pitch of spiral wire	19
Pin length (mm)	3,893
Maximum cladding temp (°C)	480-550
Cladding material	HT9

The pin outer diameter was 8.5 mm and the pin pitch was 10.0 mm in the case of the 1.4 mm of the wire diameter. The gas plenum in a fuel pin located at the upper part of the cores.

The calculation for evaluating 19 fuel rods involved 3 types of elements, 7866 nodes, 7509 elements.

Figure 2 shows the schematic configuration of the BDI calculation for 19 and 271 fuel rods of SFR by the ANSYS code.

As shown in figure 2, the fuel bundle showed the excess dispersion and displacement profile.

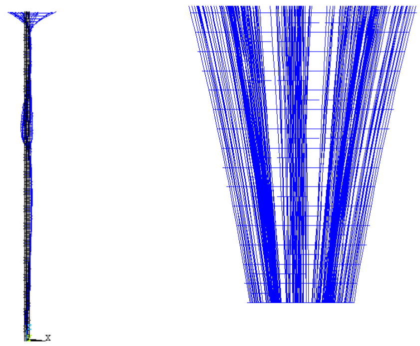

Fig. 2. Schematic configuration of the BDI calculation for 19 and 271 fuel rods

So in this paper, the preliminary sensitivity study was carried out according to parameters for analyzing the BDI of the fuel bundles.

Figure 3 shows the nodal displacement according to the temperature, the wire-wrap pitch length, and the wire-wrap diameter for 19 rods.

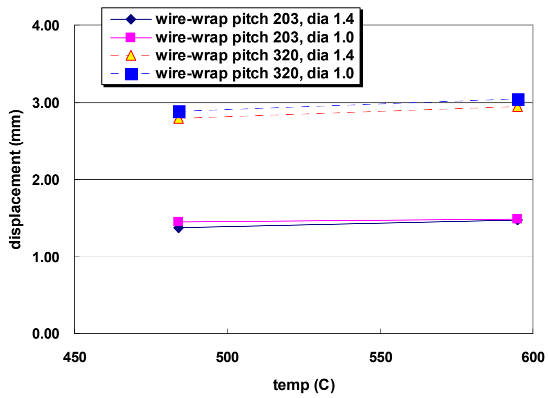

Fig. 3. Nodal displacement according to temperature, wire-wrap pitch length, and wire-wrap diameter for 19 rods

It was calculated that the nodal displacement was increased with the wire-wrap pitch length. The increase of the wire-wrap pitch length means the decrease of the turn number of the spiral wrap.

In the case of 19 wire-wrap turn for 200mm of the wire-wrap pitch, the calculated displacement was about 1.4mm. On the other hand, the calculated displacement was about 3.0mm for 12 wire-wrap turn for 320mm of the wire-wrap pitch.

The increasing of the wire-wrap pitch length affected the nodal displacement largely, because the stiffness of the fuel bundle was decreased by the increase of the length of wire-wrap pitch.

It was also calculated that the nodal displacement was increased with the wire-wrap pitch diameter and the cladding temperature. However, the difference was very small.

It showed that the effect on BDI by the wire-wrap diameter and the cladding temperature is less severe than that by the length of the wire-wrap pitch.

It was concluded that the wire-wrap pitch had a significant effect on the displacement of the BDI.

3. Conclusions

The ANSYS based model is being developed for the prediction of the BDI behavior. The fuel pin configuration model for the BDI calculation was established. The bundle duct interaction of 19 rods was preliminary analyzed to check the parameters which affect the BDI behavior.

The sensitivity study was carried out according to the wire-wrap pitch length, the wire-wrap diameter, the cladding thickness, the fuel rod diameter, the number of fuel rods, the temperature, the flux, and the thermal expansion rate of HT9 etc.

It was concluded that the wire-wrap pitch had a significant effect on the displacement of the BDI.

There are lots of uncertainties in the modeling, so this analysis model will be developed continuously. This preliminary analysis will be helpful for the establishment of the design concepts of the fuel assembly.

Acknowledgements

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