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Analysis of the Dynamic Characteristics of a Fuel Channel

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1. Introduction

Since a fuel channel consists of many parts such as fuel rods, spacer, displacer, shielding plug, etc., and the behaviors of those parts are very dependent on each other, it is difficult to accurately predict the dynamic characteristics of a fuel channel.

In this study, the dynamic characteristics of a fuel channel have been analyzed by using the finite element method. The fuel channel was modeled by using beam3 elements of the commercial FE code ANSYS. The analyses were performed for three kinds of fuel channels ‘Type A’, ‘Type B’, and ‘Type C’ under the conditions of an in-air surrounding (temp.=20^0C) and an in-water surrounding (temp.=310^0C). After the analyses, the possibility of a resonance between the fuel channel and the pressure flow which originates from the coolant pump has also been assessed.

2. FE modeling of a fuel channel

A fuel channel can be considered as a beam structure because the length of the fuel channel is much greater than its cross-sectional diameter. Therefore, the fuel channel was modeled by using the beam3 element of the ANSYS code and the mass of a fuel channel was calibrated by using the mass21 element. In order to analyze the dynamic characteristics of a fuel channel using the beam3 element, the fuel channel was divided by 24 regions according to its geometric shape. Then, the geometric data of each region such as the cross-sectional area, second moment of an inertia were calculated and the material properties and added mass in the flow were also determined.

2.1 Geometric data

Since the fuel channel is a cylindrical shaped structure, its cross-sectional area and second moment of an inertia can be calculated by using the following equation.

$$A = \frac{\pi}{4}(\phi_{out}^2 - \phi_{in}^2),$$

$$I = \frac{\pi}{64}(\phi_{out}^4 - \phi_{in}^4), \qquad (1)$$

where ϕ_{out} and ϕ_{in} are the outer and the inner diameters of each divided region of the fuel channel.

2.2 Material properties

Material properties such as the density, Young’s modulus, and Poisson ratio are provided as input data for analyzing the dynamic characteristics of the fuel channel. Since the fuel channel consists of many components, it is difficult to determine the material properties. Especially, because different components such as the fuel rods, fuel shroud, core part etc., and different materials such as stainless steel, Zr-1Nb, Zr-U etc. are mixed up in the region of a fuel assembly, the equivalent material properties should be determined in that region. Since the mass of fuel rods takes charge of 90 % of the total mass of a fuel assembly, it is reasonable to consider the fuel rod’s material properties as the equivalent material properties of the fuel assembly region. The equivalent material properties of a fuel assembly region are obtained as follows;

- Density :
  Type A: $(\rho_{equ})_{TypeA} = 7885.25 kg/m^3$,
  Type B: $(\rho_{equ})_{TypeB} = 7889.56 kg/m^3$,
  Type C: $(\rho_{equ})_{TypeC} = 7890.90 kg/m^3$.
- Young’s Modulus :
  In air (20^0C) : $(E_{equ})_{RT} = 106.5 \times 10^9 N/m^2$,
  In water (310^0C): $(E_{equ})_{OT} = 90.5 \times 10^9 N/m^2$.
- Poisson Ratio : 0.3.

2.3 Added mass in water

When the fuel channel vibrates in water, an added mass should be considered in the analysis [1]. Because the fuel channel has a cylindrical shape, the added mass by water can be calculated as the sum of the following m_1 and m_2. Here, m_1 and m_2 represent the mass per unit length and ρ_{water} is the water density at 310^0C [2].

$$m_1 = \frac{\pi}{4}\phi_{in}^2 \cdot \rho_{water},$$

$$m_2 = \frac{\pi}{4}\phi_{out}^2 \cdot \rho_{water}. \qquad (2)$$

3. Modal analysis of a fuel channel

The modal analyses of a fuel channel were carried out for three kinds of fuel channels ‘Type A’, ‘Type B’, and ‘Type C’ under two kinds of surroundings, one is an in-air surrounding of which the temperature is 20^0C and the other is an in-water surrounding of which the temperature is 310^0C. Six different boundary conditions were applied to each case and they were ‘clamp-clamp’, ‘clamp-simple’, ‘clamp-free’, ‘simple-clamp’, ‘simple-simple’, and ‘simple-free’ at both ends of a fuel channel.

Figure 1 shows the modal shape of ‘Type A’ fuel channel which is an in-water surrounding. Tables 1 and 2 show the modal analysis results when the fuel channel is ‘Type A’ and the surrounding condition is an in-water and an in-air, respectively.

The peak frequencies of the pressure fluctuation of the flow originating from coolant pump have 3 peak values. Figures 2 and 3 show the natural frequencies of the fuel channel with the 3 peak frequencies of the pressure flow. The first mode frequencies of the fuel channel, which are the most dominant mode, are much lower than that of the pressure flow so a resonance between the fuel channel and the pressure flow is not expected. The second mode shows similar results to the first mode. From this result, it is expected that there would be no resonance between the fuel channel and the pressure flow.

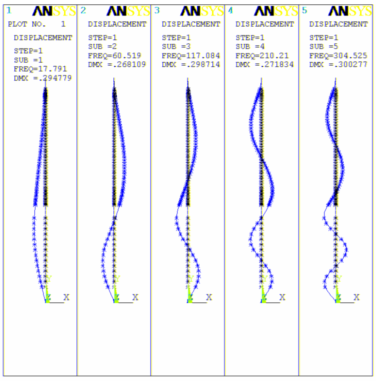

Figure 1 Modal shape of the ‘Type A’ fuel channel in-water.

Table 1 Modal Analysis Results of the ‘Type A’ fuel channel in water - Mode participation factor, and Cumulative mass fraction.

Mode	clamp -clamp	clamp -simple	clamp -free	simple -clamp	simple -simple	simple -free
1	1.000 0.723	1.000 0.749	1.000 0.603	1.000 0.805	1.000 0.855	1.000 0.512
2	0.125 0.734	0.201 0.780	0.547 0.784	0.010 0.805	0.098 0.863	0.724 0.781
3	0.452 0.882	0.413 0.908	0.416 0.888	0.371 0.917	0.324 0.954	0.405 0.865
4	0.063 0.885	0.116 0.918	0.249 0.926	0.035 0.918	0.042 0.955	0.342 0.925
5	0.288 0.945	0.240 0.961	0.232 0.958	0.227 0.960	0.175 0.981	0.213 0.948

Table 2 Modal Analysis Results of the ‘Type A’ fuel channel in air - Mode participation factor, and Cumulative mass fraction.

Mode	clamp -clamp	clamp -simple	clamp -free	simple -clamp	simple -simple	simple -free
1	1.000 0.730	1.000 0.755	1.000 0.608	1.000 0.810	1.000 0.857	1.000 0.518
2	0.120 0.741	0.198 0.784	0.547 0.789	0.015 0.810	0.096 0.865	0.715 0.783
3	0.447 0.887	0.410 0.911	0.412 0.893	0.370 0.920	0.324 0.954	0.403 0.867
4	0.058 0.890	0.111 0.921	0.245 0.929	0.038 0.922	0.040 0.956	0.336 0.926
5	0.282 0.948	0.237 0.963	0.226 0.960	0.224 0.962	0.175 0.982	0.214 0.950

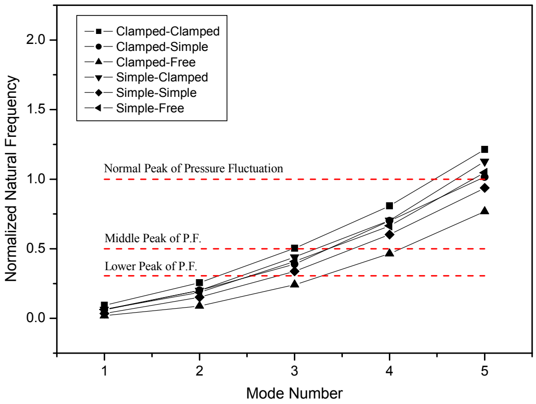

Figure 2 Natural frequencies of the ‘Type A’ fuel channel in water with peak frequencies of the pressure flow.

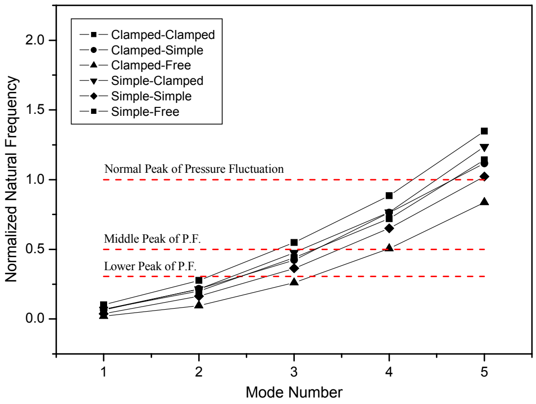

Figure 3 Natural frequencies of the ‘Type A’ fuel channel in air with peak frequencies of the pressure flow.

4. Conclusion

The dynamic characteristics of a fuel channel have been analyzed by using the finite element method and the possibility of a resonance between the fuel channel and pressure flow has been evaluated.

From the analysis results, it was found that there would be no problem from the resonance view point between the fuel channel and the pressure flow.

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[1] R. D. Blevins, Formulas for Natural Frequency and Mode Shape, 1979.
[2] IAPWS-95, Release on the IAPWS Formulation 1995 for the thermodynamic Properties of ordinary Water, 1995.