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Instability Estimation of Tube Arrays in Cross Flow

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1. Introduction

The Upper Internal Structure (UIS) for the Prototype Gen IV Sodium Fast Reactor (PGSFR) is attached to the rotatable plug of the reactor vessel head and cantilevered downward into the reactor hot pool. UIS is a porous cylindrical structure with many holes at the lateral and bottom side. Up-stream coolant passes through these holes. Also, UIS contains 2 porous horizontal structural plates and 9 CRDM (Control Rod Drive Mechanism), 6 thermocouple conduits and 7 sensor guide pipes. And many thermos couple instrument posts are attached to the bottom plates of UIS [1].

When the up-stream coolant passes through UIS, many thermos couple instrument posts attached to the bottom plates of UIS are able to vibrate due to the cross flow of the coolant. In this paper, the FIV(Flow Induced Vibration) for the thermos couple instrument posts arrays in cross flow of a 3800 MWt burner reactor was estimated by the ASME code. Thus, the optimal length of the thermos couple instrument posts can be selected considering the structural arrangement of the other components in the reactor.

2. Methods and Results

The many thermos couple instrument posts attached to the bottom plates of UIS are shown in Fig. 1 and the shape of these is shown in Fig. 2. The material is Inconel 718 and the material properties is shown in the Table 1. When the up-stream coolant passes through UIS, the thermos couple instrument posts is able to vibrate due to the cross flow of the coolant. Therefore, FIV for the length of the thermos couple instrument posts in the cross flow has to be estimated

Table 1 Material properties of Inconel 718

Material Properties	Inconel 718
weight per unit length(kg_f/m)	16.081
Modulus of Elasticity(N/m^2)	1.71034E11

2.1 Critical Velocity

The critical velocity was calculated according to ASME Sec. III Div. I Appendices N-1330 [2]. Dimensional analysis considerations imply that the onset of instability is governed by the following dimensionless groups: the mass ratio m_t/D^2 ; the reduced velocity V/fD ; the damping ratio ξ_n, measured in the fluid

$$V_c/f_nD = C(m_t(2\pi\xi_n)/\rho D^2)^a$$

where,

V_c= critical cross flow velocity (m/s)
f_n= natural frequencies of the immersed tube (Hz)
D = outer diameter of tube (m)
m_t = mass per unit length (kg/m)
ξ_n= fraction of critical damping for nth mode
ρ = fluid mass density

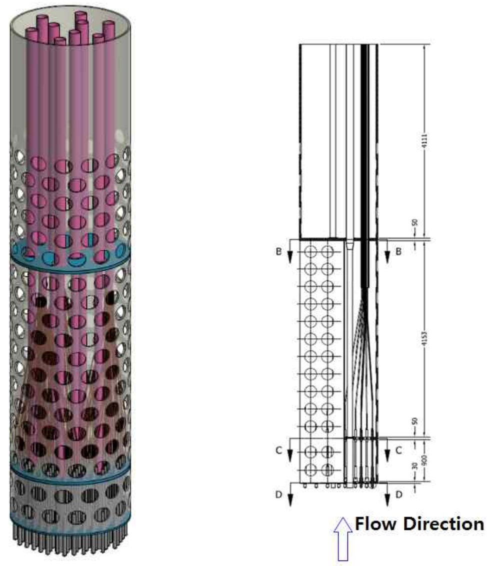


Fig. 1 UIS contained thermos couple instrument post

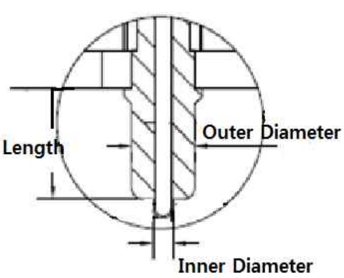
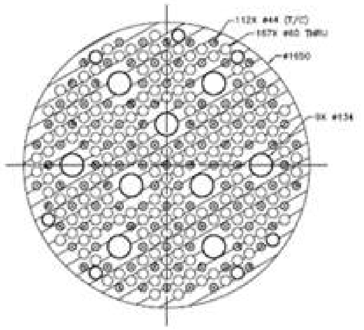


Fig. 2 Shape of thermos couple instrument post

a is determined according to tube array geometry and 0.5 value recommended by N-1331.2 is used. C value is 4.5 because of triangle array according to N-133.2 (Fig. 3).



Section D-D

Fig. 3 Triangle array of thermos couple instrument post

2.2 Natural Frequency

The thermos couple instrument post is assumed as the cantilever beam attached to the bottom plates of UIS and the end of the tube is fixed. The material of the tube is Inconel 718.

$$f_1 = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{Wl^4}}$$

where,

K_n =3.52 at first mode
E= modulus of elasticity (Inconel 718)
I = moment of inertia
W = weight per unit length of tube
l = tube length
inner diameter = 0.0127 m, outer diameter = 0.05 m

2.3 Total Mass of Tube

Total mass of tube is the structural mass per unit length plus the added fluid mass per unit length [2].

$$m_{total} = m_{tube} + m_{added}$$

m_{tube} is calculated as follow equation.

$$m_{tube} = \frac{\pi}{4}(D_0^2) \times l \times \rho_{tube}$$

m_{added} is calculated as follow equation.

$$m_{added} = \frac{\rho\pi D^2 b}{4}\left(\frac{\Delta^2+1}{\Delta^2-1}\right)$$

where,
ρ = fluid mass density (sodium : 821.65 kg/ m^3)
D= outer diameter of tube
b = tube length

$$\Delta = \frac{D_e}{D} = \left(1+\frac{0.5p}{D_0}\right)\left(\frac{p}{D_0}\right)$$

where,
p = pitch of tube array (0.13636 m)
D_0 = outer diameter of tube

2.4 Damping Value of Flow Induced Vibration

The tube damping value of FIV (Flow Induced Vibration) is shown in Table N-1311-2. This damping value is 0.002 for the thermos well.

2.5 Results of Calculation

The critical velocity was calculated for 0.086 m, 0.2 m, 0.3 m and 0.4 m length of thermos couple instrument post, respectively. The fluid velocity through UIS is 6.9 m/s. The critical velocities of calculation result was shown in Table 2.

Table 2 Critical velocity for tube length

Tube Length(m)	Natural Frequency(Hz)	Critical Velocity(m/s)	Margin
0.086	5160	460.23	66.7
0.2	954	85.09	12.3
0.3	424	37.82	5.5
0.4	239	21.32	3.1

3. Conclusions

Critical velocities for lengths of the thermos couple instrument post (0.086 m, 0.2 m, 0.3 m and 0.4 m) were 21m/s ~ 460 m/s. Since the fluid velocity is 6.9 m/s, FIV is hardly generated for the given tube length. Therefore, the selection of the flexible length of the thermos couple instrument post in the reactor is possible and such a selection is advantageous for the arrangement of the other components in the reactor.

REFERENCES

[1] K.S. Kim, Estimation for Fluid Induced Vibration of thermos couple instrument post, SFR-240-DM-302-002, Rev. 0, 2016.
[2] ASME Sec. III Div. I Appendices N-1330, Fluid-Elastic Instability, 2004.