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다목적연구로 반응도 제어장치의 제어봉에 대한 내진해석

Seismic Analysis of Absorber Rod in KMRR Reactivity Control Mechanism

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ABSTRACT

This study is a seismic analysis of absorber rod in KMRR Reactivity Control Mechanism. The model being studied is two coaxial tubes (control absorber rod and flow tube) immersed in the water and partially coupled (overlap) by water gap. The hydrodynamic mass effects by the water in each surrounding conditions are considered in the model. The natural frequencies, stresses and displacements of the system due to Safe Shutdown Earthquake are computed in the cases of in-phase modes and out-of-phase modes of two coaxial tubes. The results show that maximum stresses are well below the allowable limit and maximum displacements at the ends of both tubes in out-of-phase modes are so much that the tubes contact each other in the overlap zone.

1. Introduction

This study is motivated by the need of seismic qualification of KMRR (Korea Multipurpose Research Reactor)Reactivity Control Mechanism consisting of Control Absorber(CA) unit and Shutoff (SO) unit. Both CA unit and SO unit have the identical absorber rod (actually it is tube) which is inserted (or dropped by gravity) and withdrawn as necessary to control the reactivity of reactor.

There are lots of factors to affect the drop time of absorber rod such as ; drag forces of surrounded upward flow, mechanical frictions on the sliding surfaces, contact between absorber rod and flow tube due to flow induced vibration and safe shutdown earthquake (SSE) induced vibration, etc.

In the case of SSE, the SO unit should keep the structural and functional integrity while CA unit require only the structural integrity. One of the fuctional requirements for SO unit during earthquake is the drop time of absorber rod (within 1.5 seconds for 600mm stroke)[1].

The objective of the this study is (1) to estimate hydrodynamic mass effects on flexural vibration frequency and mode shape, (2) to check the structural integrity whether the maximum stresses are below the allowable limits and (3) to check the displacements whether these values cause the contact between absorber rod and flow tube under SSE condition.

The computer program STARDYNE[5] is used in obtaining frequencies, mode shapes, stresses and displacements.

2. Assumptions Made In Modelling

The simplifed model being studied is shown in Fig.1. The absorber rod is hydrodynamically coupled at the lower end with cylindrical flow tube and surrounding hexagonal flow tubes. The detail demensions and the material specification are as followings;

R1 = 30.0 mm
R2 = 31.25 mm
R3 = 33.5 mm
R4 = 38.0 mm
R5 = 43.37 mm : Equivalent radius of surrounding hexagonal tube
L1 = 950 mm
L2 = 170 mm
L3 = 740 mm

Material Specification

Flow Tube	: Zircalloy 4	(node 1-10)
Absorber Rod	: Hafnium	(node 11-19)
	Zircalloy 4	(node 19-22)

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For the modelling of this system, followings are assumed.

(1) Both tubes (absorber rod and flow tube) are sufficiently long in comparision with those diameters to consider the hydrodynamic effect to be in 2-dimension; the effect in axial direction can be ignored.

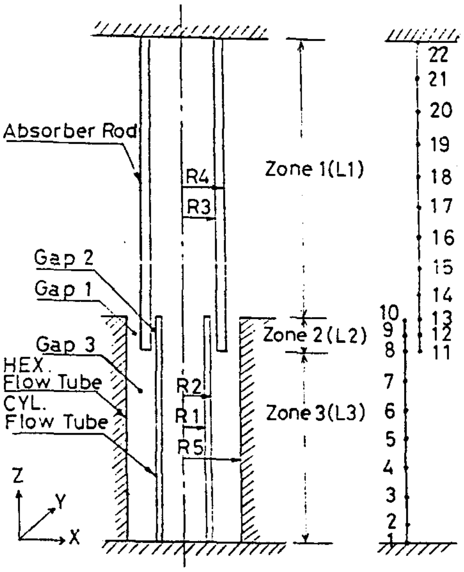
(2) The interesting aspect is only the flexural mode vibration(Circumferential mode will not be considered).

(3) Flow induced vibration is not considered.

(4) The absorber rod is surrounded by infinite stagnant water except the overlap zone with flow tubes.

(5) Surrounding hexagonal flow tubes are assumed to be a rigid cylindrical tube with a equivalent radius.

(6) The fluid is inviscid. Therefore the modal damping ratio is considered to be negligible.



a. Schematic Diagram b. FEA Model

Fig.1 Schematic Diagram and Finite Element Analysis Model of Absorber Rod/Flow Tube

3. Analysis of Natural Frequency

The absorber rod upper end can be assumed to be clamped at chimney wall in the view point of flexural mode vibration. The flow tube lower end is clamped to grid plate. Actually all of these structure are immersed in water flowing upward, but the water is assumed to be stagnant to estimate the seismic induced vibration only.

The zones and gaps as described in Fig.1 is defined to identify the hydrodynamically added mass effects due to surrounding conditions.

With the given dimensions and assumptions, the added mass per unit length in each zone can be calculated from reference [2].

(1) Zone 1 :

In this zone, absorber rod is assumed to be immersed in a finite fluid medium, therefore the added mass Ma is

$$Ma = Mp + Mv$$

$$= \gamma \pi R3^2 + \gamma \pi R4^2 \qquad (1)$$

where Mp is the physical water mass contained inside the absorber rod and Mv is the virtual water mass due to surrounding water. The γ is water density.

(2) Zone 2 :

When two tubes are coupled by fluid gap, the added virtual mass depends on the phase of modes between two tubes[3].

A. In-phase Modes

The added mass for the in-phase modes is that the physical masses in flow tube and in gap 2 plus the virtual mass in gap 1, therefore

$$Ma = Mp + Mv$$

where

$$Mp = \gamma \pi R1^2 + \gamma \pi \ (R3^2 - R2^2) \qquad (3)$$

Because the surrounding wall was assumed to be rigid, the virtual mass in gap 1 is as following ;

$$Mv = C \gamma \pi R4^2 \qquad (4)$$

where the constant C is given by

$$C = [1+(R4/R5)^2]/[1-(R4/R5)^2] \quad (5)$$

in the case that the coupled length is sufficiently long.

When the coupled length becomes finite, however, the constant C should be adjusted by a correction factor α[2]. Then the equation (4) can be substituted by the following;

$$Mv = \alpha C \gamma \pi R4^2 \quad (6)$$

The correction factor α is calculated by interpolation according to the ratio of the coupled length to diameter shown in Table 1.

B. Out-of-phase Modes

In the out-of-phase modes, it can be assumed that each tube vibrate as if the other one is rigid [3], therefore added mass is calculated for absorber rod and flow tube respectively.

The added mass for flow tube is the physical mass inside flow tube plus virtual mass in gap 2 ;

$$Ma = Mp + Mv$$

$$= \gamma \pi R1^2 + \alpha C \gamma \pi R2^2 \quad (7)$$

where

$$C = [1+(R2/R3)^2]/[1-(R2/R3)^2] \quad (8)$$

The added mass for absorber rod is the virtual mass in gap 1 and gap 2;

$$Ma = Mv1 + Mv2$$

$$= \alpha 1\ C1\ \gamma \pi R4^2 + \alpha 2\ C2\ \gamma \pi R2^2 \quad (9)$$

where

$$C1 = [1+(R4/R5)^2]/[1-(R4/R5)^2] \quad (10)$$

$$C2 = [1+(R2/R3)^2]/[1-(R2/R3)^2] \quad (11)$$

$\alpha 1$: correction factor of gap 1

$\alpha 2$: correction factor of gap 2

(3) Zone 3 :

The added mass is the physical mass inside flow tube plus the virtual mass in gap 3 and the correction factor α can be ignored (α=1) because the gap is sufficiently long in comparision with the diameter ; therefore

$$Ma = Mp + Mv$$

$$= \gamma \pi R1^2 + C \gamma \pi R2^2 \quad (12)$$

where

$$C = [1+(R2/R5)^2]/[1-(R2/R5)^2] \quad (13)$$

From the equation (1), (2), (7), (9) and (12), the numerical results of added mass per unit length in each zone is summarized in Table 2 and Table 3.

Table 1. Correction Factor α

L/2R	α
1.2	0.62
2.5	0.78
5.0	0.90
9.0	0.96
∞	1.00

L : Coupled Length, R : Outer radius of vibrating cylinder

Table 2. Added Mass for In-phase Modes

	Zone	Coeff. α	Ma [kg/m]
Absorber Rod and Flow Tube	Zone 1	N/A	8.062
	Zone 2	0.748	29.106
	Zone 3	1.0	12.521

Table 3. Added Mass for Out-of-phase Modes

	Zone	Coeff. α	Ma [kg/m]
Absorber Rod	Zone 1	N/A	8.062
	Zone 2	0.748 (α)	61.179
Flow Tube	Zone 2	0.80 (α)	38.186
	Zone 3	1.0	12.521

4. Response Spectrum Analysis

The ground response spectra for the SSE of KMRR site is 0.2g in horizontal and 0.13g in vertical direction. The floor response spectra at the clamped positions of absorber rod and flow tube is shown in Fig.2 and Fig.3. For the seismic input of in-phase mode vibration of absorber rod and flow tube, the spectra in Fig.2 which envelope those in Fig.3 are used. For the seismic input of out-of-phase mode vibration, the spectra in Fig.2 and Fig.3 are used for absorber rod and flow tube respectively.

The response spectra anasysis is calculated in three directions respectively. Therefore, the combined results are obtained by SRSS (Square Root Sum of Squares) of the values in three directions.

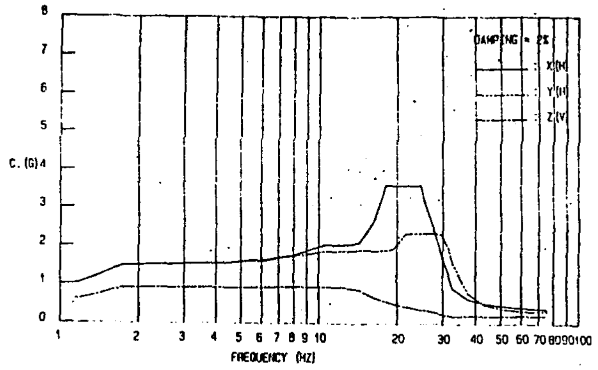


Fig. 2 Floor Response Spectra at Absorber Rod Top

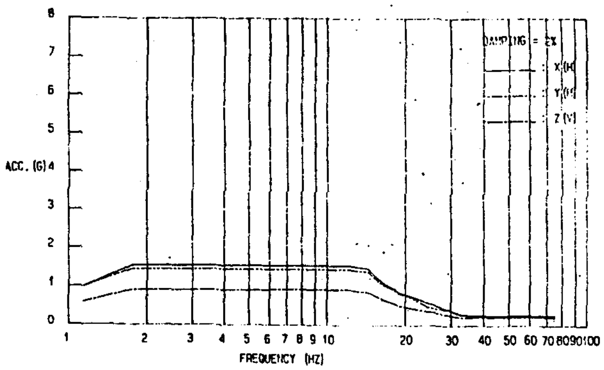


Fig. 3 Floor Response Spectra at Flow Tube Bottom

5. Results and Discussion

(1) From the model in Fig.1.b and added mass in Table 2 & 3, the natural frequencies and mode shapes of in-phase modes and out-of-phase modes are obtained as shown in the Table 4 to 6 and Fig.4 to Fig.6 respectively. It is found that the fundamental frequency ,16.326 Hz for absorber rod and 12.539 Hz for flow tube in coupled modes (out-of-phase modes) are significantly lower than that for the uncoupled mode(in-phase mode). These results shows good agreement with the general phenomena[4].

(2) The maximum stresses shown in Table 7 and Table 8 occured at the flow tube bottom for both in-phase and out-of-phase modes are within the allowable limit of 103.7 MPa.

(3) Maximum displacement, 2.96mm for in-phase modes occured at the end of absorber rod, shows no contact with surrounding hexagonal flow tubes (3.3 mm gap). But for the out-of-phase modes, the displacements of both ends are over the gap size (2.25 mm) which results in beat each other.

Table 4. Frequency of In-phase Modes

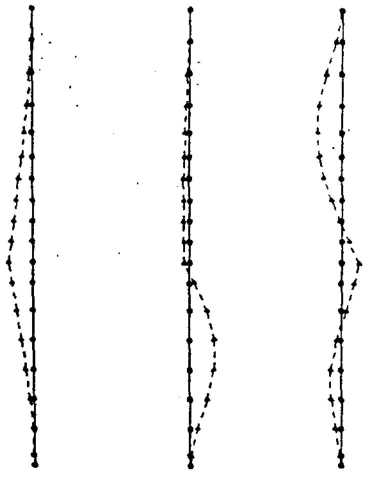
mode (n)	frequency (Hz)	max.trans. node
1	22.587	9
2	97.469	6
3	173.250	18

Table 5. Frequency of Out-of-phase Modes for Absorber Rod

mode (n)	frequency (Hz)	max.trans. node
1	16.325	11
2	150.457	18
3	425.037	20

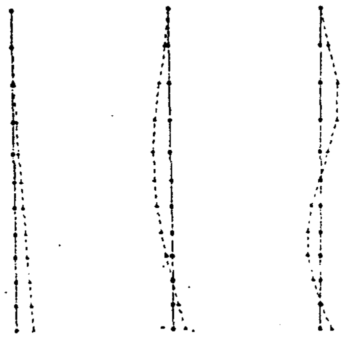
Table 6. Frequency of Out-of-phase Modes for Flow Tube

mode (n)	frequency (Hz)	max.trans. node
1	12.539	10
2	94.225	6
3	249.469	4



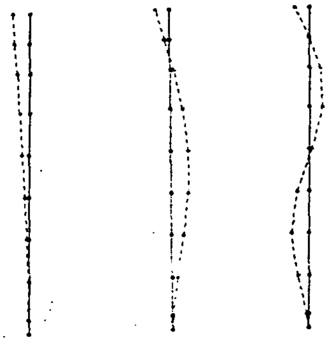
n=1 n=2 n=3

Fig.4 In-phase Mode Shapes of Absorber/ Flow Tube



n=1 n=2 n=3

Fig.5 Out-of-phase Mode Shapes of Absorber Rod



n=1 n=2 n=3

Fig.6 Out-of-phase Mode Shapes of Flow Tube

Table 7 Responses for In-phase Modes

	node	max. value
displacement	9	2.96 mm
stress	1	43.17 MPa

Table 8 Responses for Out-of-phase Modes

	Absorber Rod		Flow Tube	
	node	max. value	node	max. value
displacement	11	3.96 mm	10	4.51 mm
stress	22	39.75 MPa	1	50.25 MPa

6. Conclusions and Recommendations

(1) Hydrodynamic mass effects in in-phase modes and out-of-phase modes are significant for the system dynamic characteristics (frequencies and mode shapes). Especially frequencies in out-of-phase modes shows much lower than those in in-phase modes.

(2) The structural integrity of KMRR absorber rod and flow tube subjected to SSE is maintained since the maximum stresses are well below the allowable limits.

(3) Displacement results by response spectrum analysis show that contact is occured between absorber rod and flow tube in out-of-phase modes, while no contact in in-phase modes. The beat caused by the contact may be one of the main reasons of drop time retardation during SSE. Thus seismic test of real system in similar water flow conditions is recommended because the drop retarding factors have considerable uncertainties such as nonlinear contact which can not be evaluated by analysis.

7. Reference

(1) DR-37-31700-001, Design Requirement, Shutoff and Control Absorber Units, KMRR Rev.0, 1988

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(3) M.K.Au-Yang, "Free Vibration of Fluid Coupled Coaxial Cylindrical Shells of Different Lengths", J. Applied Mechanics, Vol.43, No.3, Trans.ASME, Vol.98, Series E, Sept. 1976, pp480-484.

(4) T.T.Yeh and S.S.Chen, "Dynamics of a Cylindrical Shell System Coupled by Viscous Fluid", J. Acoust. Soc. Am. 62, pp262-270, 1977.

(5) STARDYNE User Information Manual, General Microelectronics Corp., 1987.