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Evaluation on the Integrity of Reactor Coolant System and Pressurizer Surge Piping System

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ABSTRACT

This paper describes the vibration and stress evaluation of the reactor coolant system and the pressurizer surge piping system of Ulchin-4 nuclear power plant to verify the structural integrity during preoperational and initial startup vibration testing. The vibration levels measured at the selected points on the piping system are compared with the allowable criteria, given by ASME/ANSI OMa-1990 Standard Part 3, under various operation modes of reactor coolant pump. It is confirmed that the measured vibration levels are less than the allowable criteria and piping and its structural integrity is verified.

Introduction

High pressure and high temperature fluid induced vibration in the main components of nuclear power plants is one of the important factors which effects their reliability. The primary piping systems may be vibrated during start-up, shut down and steady-state operation of reactor coolant pump. It is a prerequisite to verify the integrity of reactor structure and its piping systems by evaluating the vibration effect. This work is called as piping verification test(PVT) that should be done just before commercial operation.[1] The vibration allowable criteria are determined by ASME/ANSI OMa-1990 Standard, Part 3 of ASME Section III & ANSI code. The criteria in normal operation is calculated according to the vibration monitoring group of ASME code. Reactor coolant piping systems, pressurizer surge piping systems are respectively classified as vibration monitoring group 1 and 2 that evaluates vibration displacement and velocity.[2] To confirm the structural integrity of primary piping systems during hot function test, the vibration of reactor coolant piping system & pressurizer surge piping system is measured and evaluated under various operation mode of reactor coolant pump. The structural integrity is verified by comparing the allowable vibration value with measured vibration level at all measuring points. The primary piping system of reactor coolant pump is shown in Fig. 1. and Fig. 2 shows the measuring points(P1~P14) of the systems.

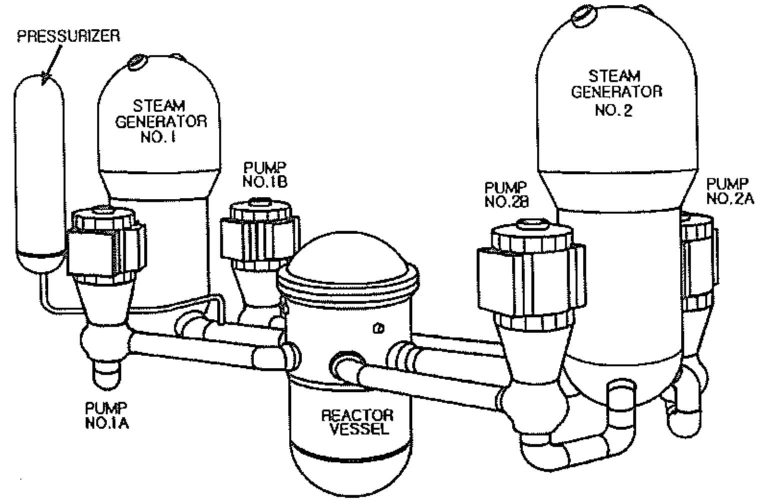
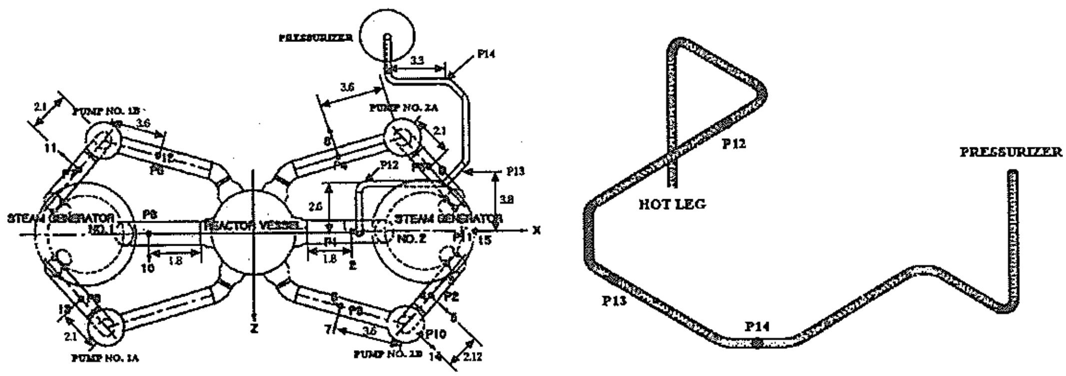


Fig. 1 Primary system of nuclear power plant



(a) reactor coolant piping system (b) pressurizer surge piping system

Fig. 2 Vibration measurement points of piping systems

Allowable displacement

The allowable displacement values based on ASME Part 3 Cord 5.1 is determined by equation(1) and (2). Model 1 and 2 as shown in Fig. 3 can be applied to Eq.(1) and (2) respectively. Eq.(2) should be used in case of model 2, specially for $L_2 \gg L_1$. (For carbon steel)

$$\triangle_A = \frac{152.4 \times L^2}{D_0 F_s C_2 K_2} \quad (\mu m, p-p) \tag{1}$$

$$\triangle_A = \frac{606.6 \times L^2}{D_0 F_s C_2 K_2} \quad (\mu m, p-p) \tag{2}$$

where, L, D_O, F_s, C_2K_2 are pipe length(ft), outside diameter(in), stress reduction factor(=1.3), peak stress indices respectively.

Table 1 Operation mode of hot function test

Mode	Condition	Pump 1A	Pump 1B	Pump 2A	Pump 2B
1	Background	×	×	×	×
2	Steady State	×	×	×	○
3		×	×	○	○
4		○	×	○	○
5	Transient	○	×	○	STOP
6		○	×	○	START
7	Steady State	○	○	○	○
× : No-operation, ○ : Operation					

The allowable displacement level of reactor coolant piping systems is based on the ASME Boiler and Pressure Vessel Code Nuclear Power Plant Components Division 1 Subsection NB & ASME/ANSI OMa-1990 Standard, Part 3. K_2 and C_2 are dependent to Table NB-3681(a)-1 and NB-3683.

Allowable velocity

The expression for allowable velocity based on ASME Part 3, Item 5.2.2.1 is

$$V_{allow} = \frac{C_1C_4}{C_3C_5}\frac{3.64\times10^{-3}(S_{el})}{aC_2K_2} \tag{3}$$

where,

V_{allow} = allowable velocity, in/sec

S_{el} = 0.8 S_A, where S_A is the alternating stress at 10^6 cycles or S_A at 10^{11} cycles of the BPV Code. The user shall consider the influence of temperature on the modulus of elasticity.

a = allowable stress reduction factor

The secondary stress index C_2 and the local stress index K_2 are associated with the point of maximum velocity. This velocity criterion is consistent with the deflection criterion for a fixed end beam at resonance in the first mode.

C_1 = a correction factor to compensates for the effect of concentrated weights along the characteristic span of the pipe

C_2K_2 = stress indices as defined in the ASME Code

C_3 = a correction factor accounting for pipe contents and insulation

$$= (1.0 + \frac{W_F}{W} + \frac{W_{INS}}{W})^{1/2}$$

where,

W = weight of the pipe per unit length(lb/ft)

W_F = the weight of the insulation per unit length(lb/ft)

= 1.0 for pipe without insulation and either empty or containing steam

C_4 = correction factor for end conditions different from fixed ends and for configurations different from straights spans

= 1.0 for a straight span fixed at both ends, but conservative for any practical end conditions for straight spans of pipe

= 1.33 for cantilever and simply supported pipe span

= 0.74 for equal leg Z-band

= 0.83 for equal leg U-band

C_5 = correction factor to account for off-resonance forced vibration, equal to the ratio of the first natural frequency of the piping spa to the measures frequency for ratios between 1.0 to 2.0. For ratios greater than 2.0, the C_5 factor is herein undefined. For ratios less than 1.0, the C_5 correction factor equals 1.0.

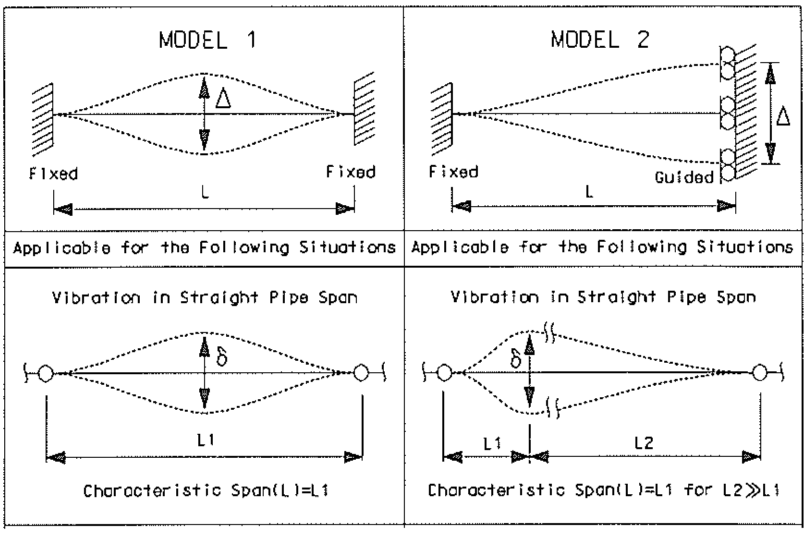


Fig. 3 Determination of span lengths and deflection models

S-N curve as shown in Fig 4 is used for evaluating the endurance alternating stress considering design fatigue under 10^{11} stress cycle in the case of stainless steel life. With the variables C_1, C_2K_2, C_3, C_4, C_5, the allowable peak velocity is calculated as 298.6mm/s, peak for pressurizer surge line.[3)]

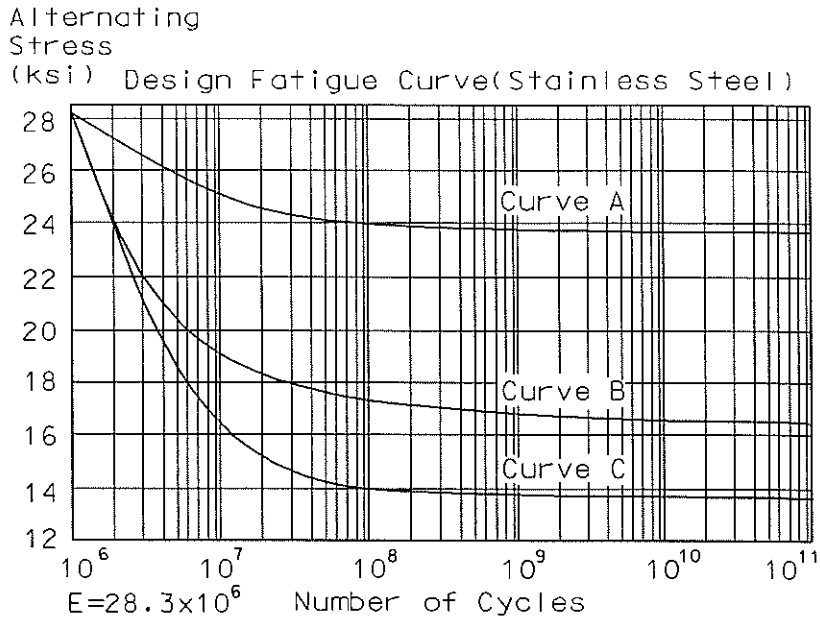


Fig. 4 Design fatigue curves from ASME Code

Testing

Fig. 5 shows the block diagram of the experimental setup. The accelerometer as shown in Fig. 6 are installed at the maximum vibrating positions which are predicting or experienced past in the reactor coolant pump piping system. The vibrations of axial, horizontal and vertical directions are measured at these points. Table 2 shows the specifications and functions of the device used to measure and analyze.

Analysis

The raw vibration data obtained from plant was processed to evaluate for the time and frequency functions. The raw acceleration signals are input to A/D of HP35650 front-end, then transmitted to HP9000-715/64 through HPIB. The high pass filter and generalized hamming window are used and the frequencies less than 2Hz are cut off for proper data acquisition.[4] The processed acceleration signals are first single integrated for velocity and then double integrated for displacement signals. Finally, the velocity and displacement signals are evaluated with the allowable criteria.

Measurement results and estimation

Table 3 shows the vibration analysis results for all measurement points. Fortunately, the vibration analysis results for piping systems are satisfied for the allowable criteria. The peak frequency of the steady-state data in the mode 7 are within between 2 ~ 20Hz and pump operating frequency of 20Hz as shown in Fig. 7(b) is appeared dominantly at the measurement points near pump, but other measuring points are showed sub-harmonics of 20Hz that is characteristics of piping. The level is also much lower than pump operating frequency in the steady state. It means that there isn't possibility of resonance.

For the pressurizer surge piping system, the integrated velocity signals are less than the allowable criterion(154.94 *mm/s*, peak). Fig. 7 shows the displacement and frequency signal of the reactor coolant piping system and the velocity signal of the pressurizer surge piping system.

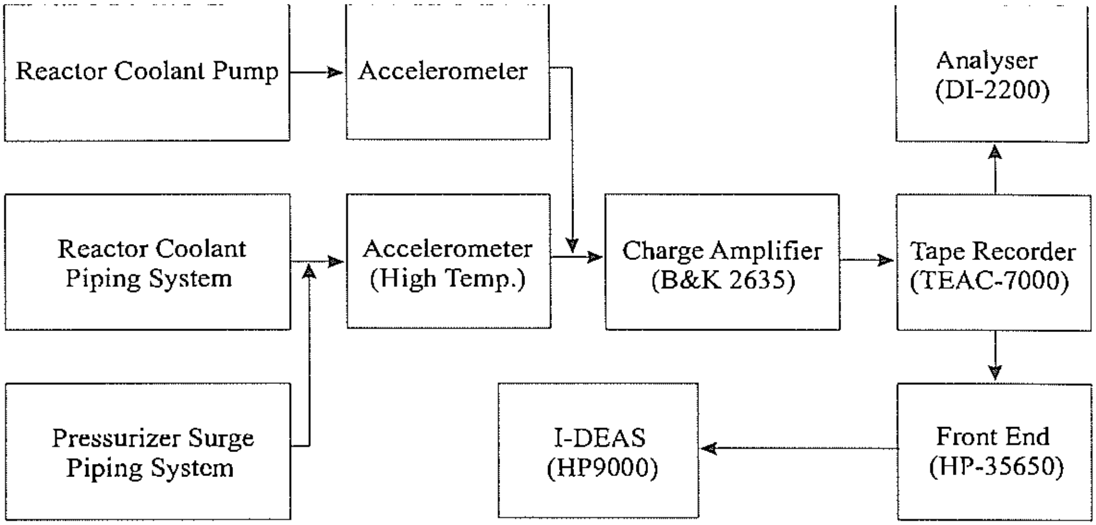


Fig. 5 Block diagram of the experimental & analytical setup

Table 2 The equipment used in measurement and analysis

Equipment name	Specification	Model No.
Accelerometer	Freq. range : 0.5 - 2800Hz Sensitivity : 20pC/g Temp. range : -54 ~ 620℃	Vibro-meter Type CA-905
Charge amplifier	Transformation to acceleration, velocity, displacement	B&K type 2635
Tape recorder	21 channel	TEAC XR-7000
Analyzer	Portable FFT	DI-2200
Workstation		HP 9000-715/64
Data acquisition system	A/D Conversion	HP35650 Front end
Software	Signal analysis	I-DEAS(T-DAS)

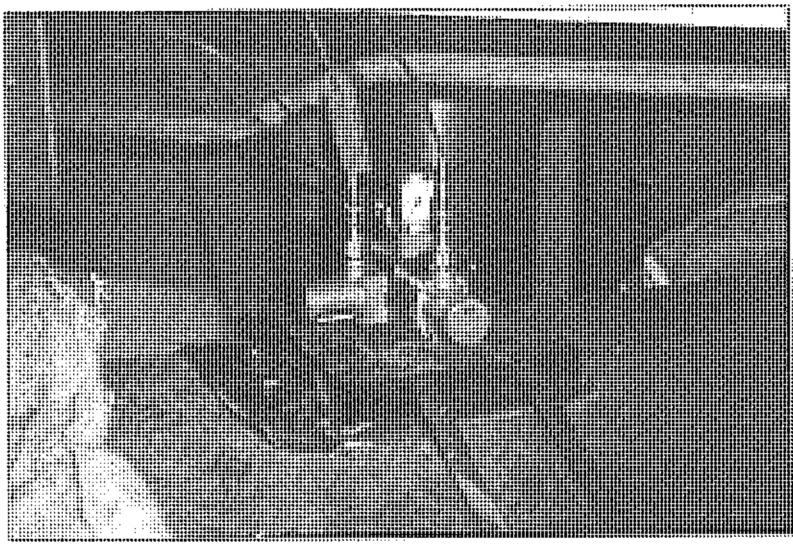
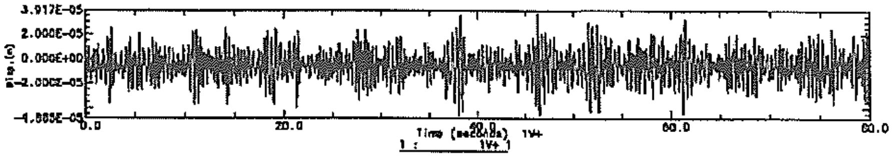


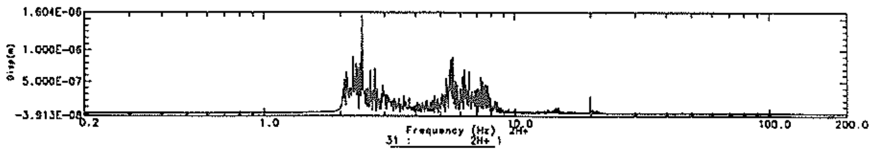
Fig. 6 Accelerometer installed at special mounting block

Table 3 Measured vibration level and allowable criteria

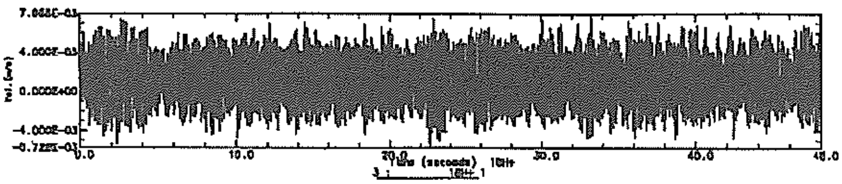
System	Meas. point	I.D	Mode 2	3	4	5	6	7	Allowable Criteria
reactor coolant piping system (μm, p-p)	P1	1	59	37	43	44	44	46	127.0
		2	26	36	31	31	31	34	152.4
		3	40	25	43	25	36	31	203.2
	P2	4	50	52	63	41	38	48	101.6
		5	31	28	59	40	33	39	254.0
	P3	6	46	39	51	41	79	64	228.6
		7	31	40	45	47	127	40	228.6
	P4	8	37	63	50	45	81	39	228.6
	P5	9	39	25	33	42	37	38	203.2
	P6	10	39	32	37	37	41	37	152.4
	P7	11	33	42	58	61	56	22	254.0
	P8	12	25	55	41	35	66	88	228.6
	P9	13	27	30	31	39	50	32	151.6
reactor coolant pump	P10	14	14	7	8	-	-	7	-
steam generator	P11	15	5	3	2	4	3	5	-
pressurizer surge piping system (mm/s, peak)	P12 Ver.	-	3.7	6.0	9.3	4.3	3.2	7.1	
	P12 Hor.	-	3.7	4.8	8.0	5.9	4.8	7.8	
	P13 Ver.	-	6.3	4.4	6.9	10.4	16.4	6.8	154.9
	P13 Hor.	-	7.9	6.1	8.5	19.2	52.1	7.6	
	P14 Ver.	-	5.1	3.8	9.4	4.7	2.6	7.8	
	P14 Hor.	-	5.5	6.4	10.3	8.0	5.8	11.6	



(a) displacement signal for the reactor coolant piping system during the mode 7



(b) spectrum for the reactor coolant piping system during the mode 7



(c) velocity signal for the pressurizer surge piping system during the mode 7

Fig. 7 The signal of the time and frequency domain for reactor coolant & pressurizer surge piping system

Conclusions

The structural integrity of primary nuclear system is verified by confirming that measuring vibration levels are much lower than the allowable criteria.

References

1. ANSI/ASME OMa-1990, Part 3, "Requirements for Preoperational and Initial Startup Vibration testing of Nuclear Power Plant Piping Systems", 1990
2. "ASME Boiler and Pressure Vessel Code Nuclear Power Plant Components Division 1 Subsection NB", 1995
3. 울진원자력본부, "실험절차서 4P-H-431-09", 1997
4. R. B. Randall, B. Tech., B. A., "Frequency Analysis", pp 146-161, 1987