FIELD VIBRATION TEST RESULTS AND DESIGN FOR REACTOR COOLANT PIPING SYSTEMS OF ATR "FUGEN"

T. IGARASHI, K. ARAI

Mitsubishi Atomic Power Industries, Inc., Nuclear Development Center, 1-297, Kitabukuro-Machi, Omiya City, Saitama Pref. 330, Japan

K. FUJITA

Takasago Technical Institute, Mitsubishi Heavy Industries, Inc., 1-1, Shinhama 2-chome, Arai-cho, Takasago 26, Hyogo Pref., Japan

In most Japanese Nuclear Power Plants, the field vibration test on the important piping systems has been performed to verify the appropriateness of the seismic design and the integrity of the pipe work.

For a prototype Heavy-Water Reactor "FUGEN" (165-MWe heavy-water-moderated, boiling light-water-cooled pressure tube reactor, developed along one of the Japan's national projects, and reached criticality on March, 1978), the reactor coolant piping systems are connected with the pressure tube, the steam drums and the recirculation pumps. The steam drums are set in the top level and the recirculation pumps in the bottom level. This layout is complicated in comparing with other type of Reactors.

The seismic analysis of the main piping systems in the FUGEN was performed by means of the model analysis method using the floor response spectrum.

The vibration tests of the main piping systems were carried out by using the electromagnetic exciters after construction of the plant, as one of the functional test programs. In these vibration tests, the dynamic characteristics (eigenfrequencies, damping factors and mode shapes) were measured.

Through these tests and analyses, it was confirmed that the reactor coolant piping systems of the FUGEN were designed and constructed safely and properly.

1 Introduction

The purpose of the field vibration test for the piping system is confirming the seismic design adequacy and the integrity of the pipe work by means of the forced excitation experiments.

These tests covering the main piping systems in the FUGEN were carried out in September 1977. This paper describes the test results and the seismic analyses of the reactor coolant piping systems and the feed water piping systems which are classified as the most important systems, i.e., class A in accordance with Japan's seismic design criteria. The reactor coolant system consists of two independent cooling circuits. Two recirculating pumps in both circuits including a manifold setting in a lower level, are suspended by four down-comers from the steam drum in the top level. Figure 1 shows a vertical section of the reactor coolant system and Figure 2 shows a picture of the vibration test. A brief specification of the piping system tests is shown in Table I.

2 Forced Vibration Test

2.1 Outline of the Test

The forced vibration test using an electro-magnetic exciter was mainly employed, and the wire-cutting excitation was employed in an additional test, in order to excite the piping systems.

By gradually varying the frequency of the exciting force, the significant modes of the test piping systems could be excited individually and its response could be detected. This sinusoidal exciting force was conservatively limited to 100kg for the reactor coolant piping systems and 50kg for the feed water piping systems to avoid exceeding the design limitation. The acceleration response of the piping systems was measured by accelerometers attached to the systems at about 50 locations. Figure 3 and Figure 4 show exciting points and the schematic of the test piping systems.

The field vibration tests of the FUGEN were performed at night to avoid the unfavorable influence such as background noise and unexpected vibration. The measuring system for the field vibration test is outlined in Figure 5.

2.2 Measurement of Dynamic Characteristics

The dynamic vibration characteristics were measured by the following means;

(1) Eigenfrequency

The sweep sinusoidal exciting force which varies in the frequency range of 2 ~ 30Hz is constantly applied for about 30 minutes at an excited point of the test piping systems and the vibration response waves are recorded by a data recorder. The observed vibration response waves are analyzed by a real-time analyzer to obtain the response spectra, and the eigenfrequency is given by the peak resonance frequency of the response spectra which are recorded by a X-Y recorder.

(2) Vibration Mode

The displacement and the phase of each measuring point for the mode shape of resonance frequency are obtained from the vibration response waves comparing with the forced excitation waves, both of which are recorded on an oscillograph simultaneously.

(3) Damping Factor

As a reference to the significant modes of vibration, the typical damping factor is derived from the free damped vibration waves.

3 Seismic Analysis

3.1 Theoretical Analysis

The eigen value and dynamic response analyses of the main piping systems were carried out by using a computer code which has been based on the stiffness matrix method. The eigenfrequency is given in equation (1) and the maximum acceleration A is calculated by the root mean square method using the floor response spectrum given by equation (2).

$$[K]\{Xo\} = \omega^2[M]\{Xo\} \qquad (1)$$

$$A = \sqrt{\sum_{i=1}^{n} \{Bi \cdot Sa(\omega_i)\}^2} \qquad (2)$$

where $[M]$: mass matrix $[K]$: stiffness matrix

ω : circular frequency $\{Xo\}$: eigen vector

Bi : participation factor $[\beta_{i1}, \beta_{i2} \cdots \beta_{i6}]$

$Sa(\omega_i)$: seismic response spector (floor response)

3.2 Analytical Model

Two analytical models of the piping test were simplified as shown in Figures 3 and 4. The three-dimensional finite element models which consist of beams and pipe elements, were used for the seismic analysis. To provide the floor response spectrum, three kinds of input waves EL CENTRO (1940, NS), GOLDEN GATE PARK (1957, S80E) and TAFT (1952, S69E) were normalized to the intensity of 0.25g and were applied to the base mat of the reactor building. The predominant period of the reactor building was 0.30 second. Summary of the results of eigenvalue analysis in the test piping systems is shown in Tables II and III.

4 Test Results

Test results of eigenfrequencies and damping factors for modes are shown in Tables II and III. These show that the measured eigenfrequencies were generally in good agreement with the analytical values. The typical response spectra are shown in Figures 6 and 7.

For the piping being only adjacent to recirculating pump, an additional wire cutting test in spite of the sweep sinusoidal test was carried out because the resonance frequencies did not appear clearly. As the result of the wire cutting test, the eigenfrequency of 11~14Hz and damping factor of 6~8% were obtained as shown in Figure 8.

When the sweep sinusoidal test for the feed water piping systems was performed separately in the directions of X and Z, only a slight difference was observed between the both resonance frequencies of X and Z directions as shown in Figure 9.

Though the calculated and experimentally obtained eigenfrequencies and mode shapes in only low frequency modes for the reactor coolant piping were close to each other, it was difficult to make a correspondence between the calculated and experimentally obtained modes in higher frequency region in the seismic analysis. Figures 10 and 11 show one example of the mode shapes analyzed in the seismic model and measured by the forced vibration test.

5 Discussion

The results of the test showed that the measured eigenfrequencies were in good agreement with the analytical values and were 2 to 3 times higher compared with the predominant frequency (3.3Hz) of the reactor building, and that the damping factors of the test piping systems were greater than the value (0.5%) used in the seismic analysis. It was therefore confirmed that the main piping systems of the FUGEN were designed and constructed safely and properly, by

comparing the above results with the analytical values.

However, the experimental results described in this paper were obtained using clamped attachments to avoid the non-linear vibrational problems caused due to the clearance associated with the seismic supporting elements, which was not considered in the analyses. Though this non-linearity would be disregarded in the case of the strong excitation of actual earthquakes, this problem should be reviewed and evaluated by means of appropriate experiments and practical analyses in order to accomplish more reliable seismic design in the near future.

References

[1] SHIMA, S., AKEBI, M., "The FUGEN Project-Construction and Startup" Second Pacific Basin Conference, Tokyo, Japan (September 25-29, 1978)

[2] SHIMA, S., AKEBI, M., "Engineering Design Features of FUGEN" International Nuclear Industries Fair, Basel, Switzerland (October 16-21, 1972)

Table I OUTLINE OF PIPING SYSTEM

		Reactor Coolant Piping Systems		Feed Water Piping Systems
Design Temperature	°C	296		235
Design Pressure	kg/cm^2 g	82		82
Pipe Outside Diameter	mm	Down-comer	356	267
		Pump Inlet	508	
		Pump Outlet	406	
Material		Austenitic Stainless Steel		Austenitic Stainless Steel

Table II EXPERIMENTAL AND ANALYTICAL RESULTS OF REACTOR COOLANT PIPING SYSTEM

Analytical Results Eigenfrequency (Hz)	Experimental Results Eigenfrequency (Hz)	Damping (% of critical)	Superior Mode Model No.	Direction	Percent Error (%)
12.27	13.5	6	7	X	10
12.31	12.5	8	13	Z	2
12.75	12.0	1.7	3	X	6
13.00	12.5	6	13	X	4
13.11	11.1	6	7	Z	15
17.94	16.2	3.1	2	Z	10
18.71	18.7	1.0	6	Z	0
19.50					
20.1	19.6	7.5	6	X	3

Table III EXPERIMENTAL AND ANALYTICAL RESULTS OF FEED WATER PIPING SYSTEM

Analytical Results Eigenfrequency (Hz)	Experimental Results Eigenfrequency (Hz)	Damping (% of critical)	Superior Mode Model No.	Direction	Percent Error (%)
8.24	8.6	0.7	7	X	4
14.42	14.8	2.1	9	X	3
15.67	17.0	4.5	7	Z	8

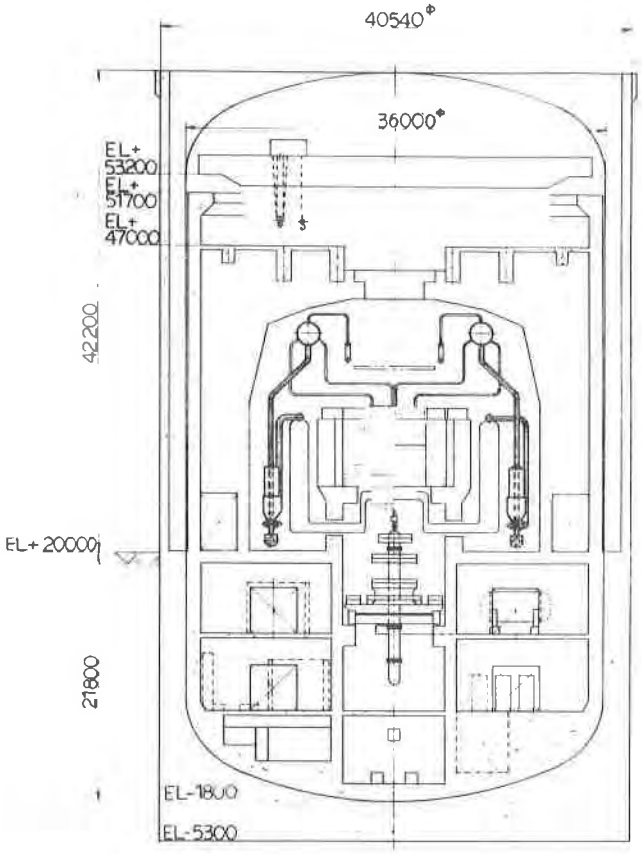

Figure 1 General View of Reactor Coolant System

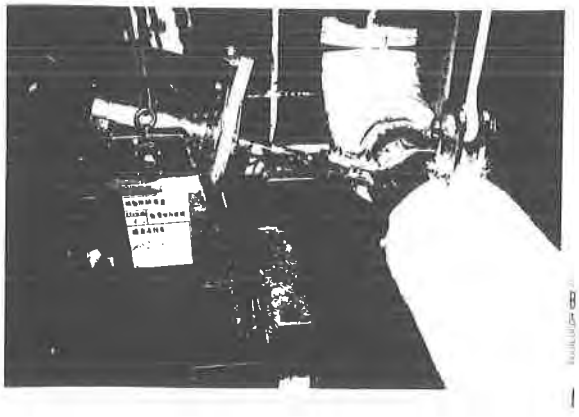

Figure 2 Vibration Test of Feed Water System

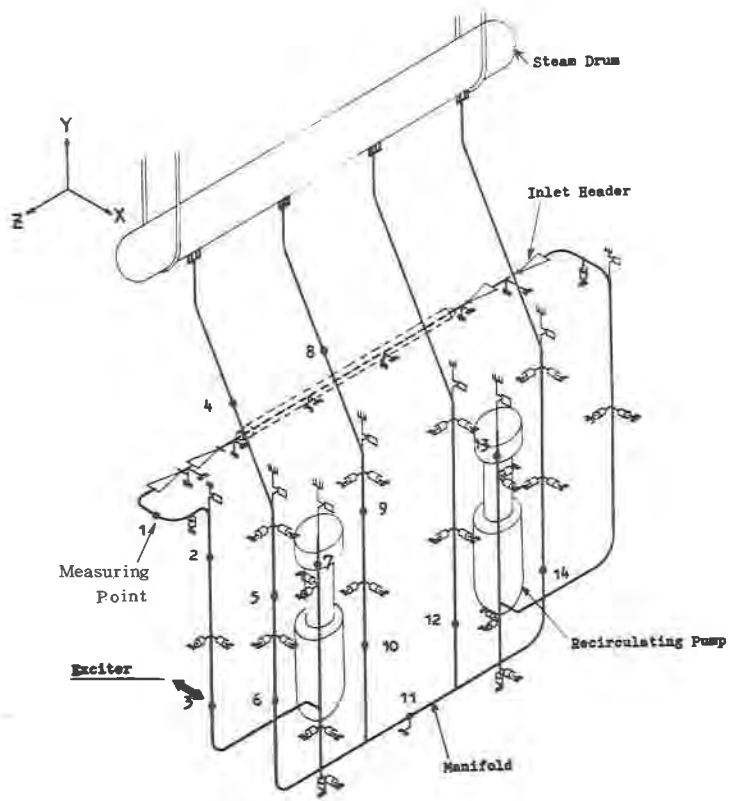

Figure 3 Schematic of Reactor Coolant Piping System

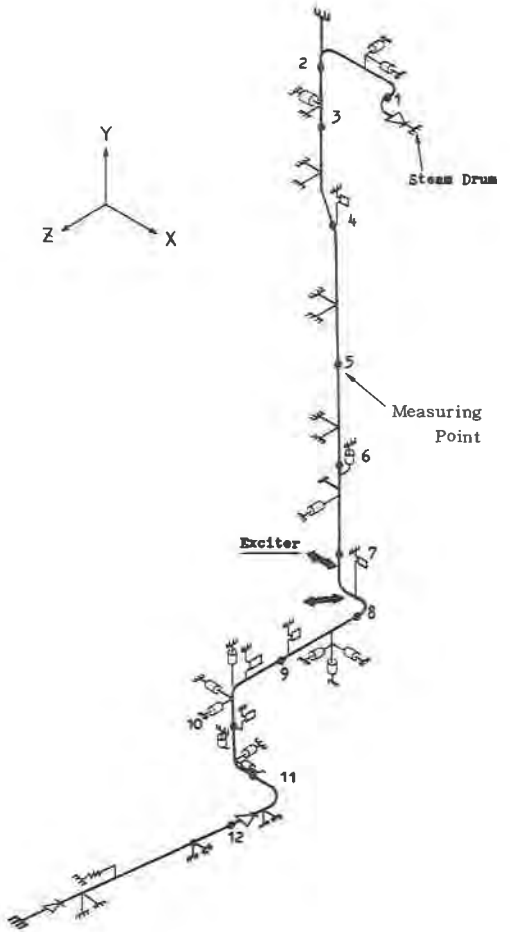

Figure 4 Schematic of Feed Water Piping System

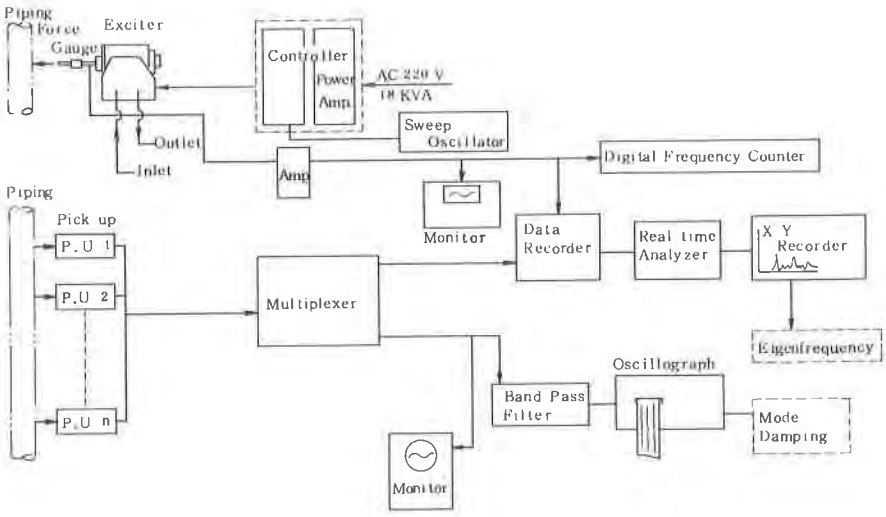

Figure 5 Measuring System for Field Vibration Test

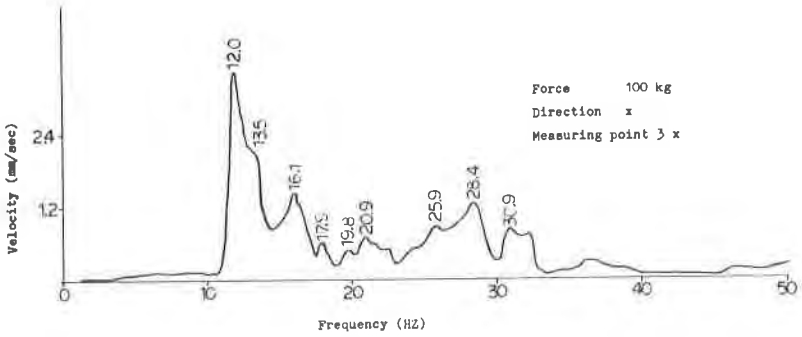

Figure 6 Reactor Coolant Piping Response Spectrum

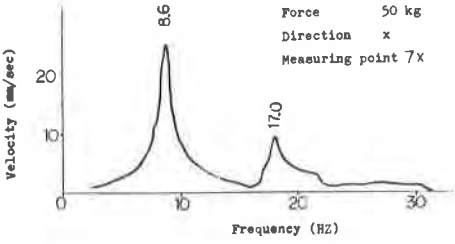

Figure 7 Feed Water Piping Response Spectrum

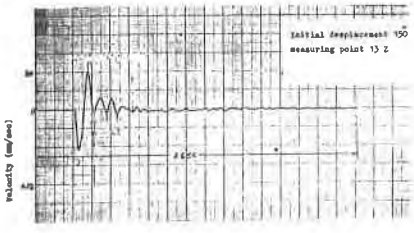

Figure 8 Free Damping Wave of Recirculating Pump

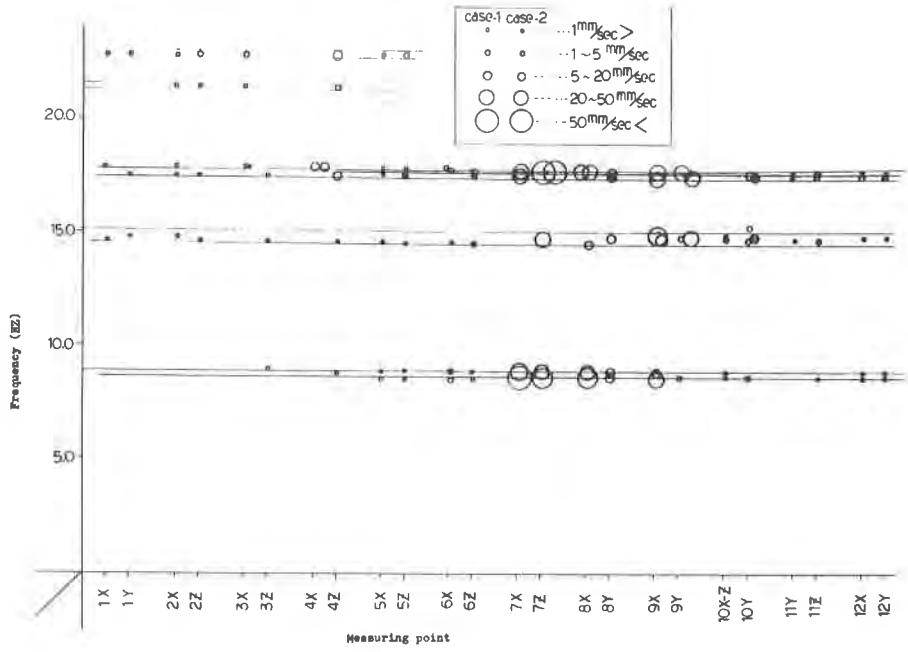

Figure 9 Response Comparison Between Exciting Direction X and Z of Feed Water Piping System

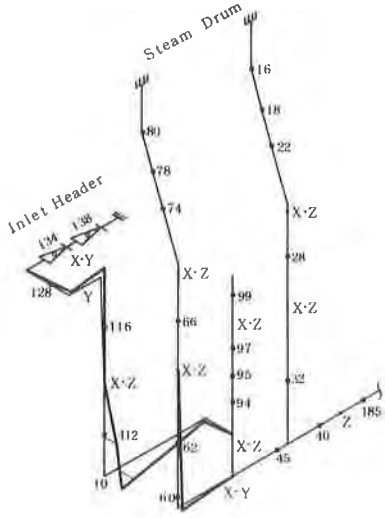

Figure 10 Calculated Mode Shape at 12.27 Hz

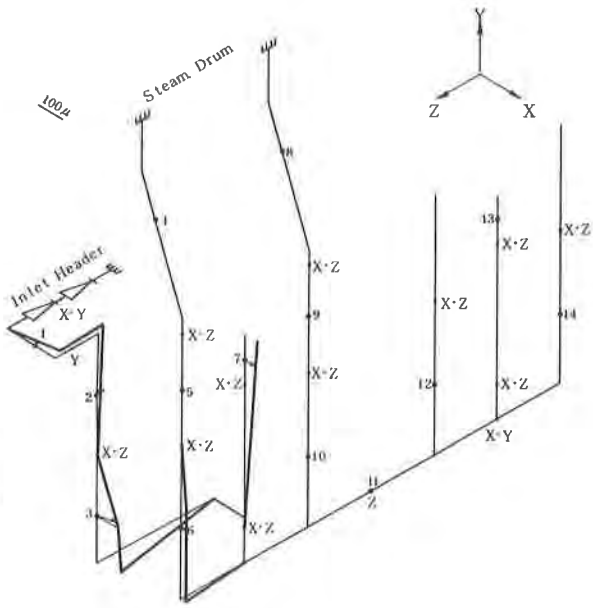

Figure 11 Experimental Mode Shape at 12 Hz