An Experimental Investigation of a Class of Nuclear Power Plant Valves

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Abstract

Experimental and analytical studies of the response of two typical nuclear power plant valves under a variety of dynamic environments are presented. A 4-inch and a 6-inch globe valve were investigated to determine characteristic structural dynamic response relationships between various magnitudes and types of forced excitation. The dynamic loads consisted of swept-sine, sine dwell, random, and shock excitation. Different magnitudes and directions were applied with each type of excitation. The experimental measurements were analyzed by introducing suitable dimensionless response parameters and appropriate excitation intensity measures that clearly indicate the presence of nonlinear response phenomena. Some guidelines and areas of concern for the qualification testing of similar equipment are given.

1. Introduction

The dynamic qualification of mechanical equipment, such as pumps and valves to be used in nuclear power plants, is a complex process that depends on many factors. Such factors include the particular function and characteristics of the equipment, the nature of the dynamic load to which it is subjected, and the location of the equipment within the plant.

A question of profound interest to regulatory agencies and design engineers regarding the seismic qualification of pumps and valves is whether the specimen has significant structural frequencies within the earthquake spectral bands. Mechanical equipment that can be shown by testing not to have natural frequencies within the seismic range can be analyzed as a "rigid body," thus simplifying considerably the qualification procedure for that particular item of interest. Consequently, it is important to establish suitable criteria for the dynamic qualification testing of equipment such as pumps and valves so as to obtain reliable data concerning the behavior of the test item under seismic and other dynamic environments.

As a step in the development of improved guidelines and criteria for meaningful testing and analysis of intricate mechanical equipment used in nuclear power plants, two typical globe valves of similar design (one a 4-inch size and the other a 6-inch size) were dynamically tested.

2. Experimental Tests

2.1 Specimens

The 4-inch valve weighed approximately 75 kg and the 6-inch valve weighed about 115 kg. Detailed information regarding the test specimens is given in references [1,2].

2.2 Instrumentation

Each test specimen was instrumented with eleven accelerometers and four strain gages. A sample instrumentation configuration is shown in fig. 1. The criteria for selecting appropriate locations were based on the estimated mode shapes of the test specimen. Accelerometer block D was mounted inside the specimen on its valve seat.

2.3 Test Fixture

The base of the test fixture consisted of a large steel ground plate attached to either the electrodynamic shaker or the shock machine. Two steel adaptor plates were then mated to the existing flange-bolt pattern of the valve and the ground plate. The fixture was designed and tested to ensure that its own natural frequencies were considerably higher than the lower frequencies of the valves.

2.4 Dynamic Tests

All test operations were performed in accordance with procedures outlined in references [3,4].

2.4.1 Swept- and Dwell-Sinusoidal

Each test specimen was subjected to a swept-sinusoidal excitation of different magnitudes and sweep directions in each of its two orthogonal test axes. Additionally, each test specimen was subjected to a 30 sec resonant dwell test for each of the first three or more major structural modes observed below 300 Hz in the data obtained from the swept-sine testing.

2.4.2 Random

Each test specimen was subjected in two of its orthogonal axes (Y and Z) to three different random vibration spectrums for one or two minutes along each test axis.

2.4.3 Shock

Using a medium-weight shock testing machine as described in [4], each test specimen was subjected to three different shock levels along both the longitudinal (Y) and transverse (Z) axes.

3. Analysis of Results

3.1 Data Reduction

The following data analyses were accomplished for the control accelerometer and response instrumentation installed on the test specimen.

3.1.1 Time Histories

Sinusoidal and shock data were bandpass filtered and plotted versus time. Sample results are shown in fig. 2.

3.1.2 Transmissibility Ratio

Transmissibility plots were generated for all swept-sine data by normalizing the response acceleration at a given location with respect to the input acceleration.

3.1.3 Power Spectral Density

PSD plots were generated for all random test data by using a 6 Hz filter over an analysis range of 20 to 2000 Hz.

3.1.4 Shock Spectrum

A 1/10 octave bandwidth analysis was performed for all shock test data over the range of 10 Hz to 5 kHz.

The complete laboratory data obtained from the tests on the 4-inch and 6-inch valves were reduced in the manner discussed above, and are available in references [1,2].

3.2 Normalized Results

In order to evaluate the effect of the excitation level on the response of the two tested globe valves and to detect the presence of nonlinear characteristics, each valve response was analyzed and reduced to dimensionless form by normalizing the absolute response of each valve location (station) by an appropriate excitation quantity which was a measure of the intensity of the dynamic load. The form of the dimensionless quantities was chosen so that response curves for a linear system corresponding to different excitation levels would coalesce (collapse into a single curve); thus, any deviation between curves for different load levels would clearly herald the presence of nonlinear phenomena.

For the swept-sine excitation, the peak response at a given frequency was divided by the peak amplitude of the input acceleration at that frequency. This resulted in the dimensionless transmissibility plots.

In the case of the stationary random excitation, the PSD of the response at a given frequency was normalized by dividing it by the PSD of the input (constant with respect to frequency) corresponding to the test level.

In the case of shock excitation, the acceleration shock spectra were divided by an intensity index $I = \int S_V(\omega)d\omega$, where S_V is the velocity spectrum of the shock pulse whose time history is shown in fig. 2.

Sample dimensionless plots for representative stations along both valves under different types of dynamic environments and excitation directions are presented in figs. 3-5. For the sake of clarity, only the dominant peaks of the various response curves are plotted in these figures.

3.3 Comparison of Results

The fundamental structural mode of vibration for the 4-inch and 6-inch valves was a flexural cantilever beam mode with a frequency of 18 Hz and 8 Hz, respectively.

Referring to the dimensionless response plots discussed above, it was found that with each of the three different classes of tests done, the dimensionless response quantities of both valves clearly disclosed the presence of significant nonlinear behavior. Also, different classes of dynamic tests revealed a different "portrait" of the spectral content of the valve response.

4. Conclusions

On the basis of the experimental studies reported herein, it was found that erroneous conclusions may be reached regarding the dominant natural frequencies of test items, similar to the ones investigated, if care is not exercised in specifying both the nature and level of dynamic test environments.

5. Acknowledgements

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References

[1] MASRI, S.F., STOTT, S.J., Response of a 4-Inch Nuclear Power Plant Valve to Dynamic Excitation, Report No. CE 79-13, NUREG/CR 1317, University of Southern California, Los Angeles, California, December 1979.

[2] MASRI, S.F., STOTT, S.J., Response of a 6-Inch Nuclear Power Plant Valve to Dynamic Excitation, Report No. CE 80-04, NUREG/CR 1644, University of Southern California, Los Angeles, California, September 1980.

[3] Environmental Test Methods, Military Standard MIL-STD-810C, Department of Defense (ASD/ENYESA), Wright-Patterson Air Force Base, Ohio, 1975.

[4] Shock Tests, H.I. (High Impact); Shipboard Machinery, Equipment and Systems, Requirements for Military Specification MIL-S-901C, Department of Defense (U.S. Navy), Washington, D.C., 1963.

ACCELEROMETER BLOCKS

Block	Coordinates (in.) X	Y	Z
A	0	+35.44	0
B	+2.95	+15.45	0
C	+2.87	+6.0	0
D	0	-1.5	0

STRAIN GAGES

Gage	Coordinates (in.) X	Y	Z
1	0	+5.5	-1.0
2	0	+5.5	+1.0
3	0	+8.25	-1.0
4	0	+8.25	+1.0

ACCELEROMETER LOCATIONS

Number	Block	Aspect
1	Control F	+Z
2	B	+Z
3	B	+X
4	D	-Y
5	D	+Z
6	D	+X
7	C	+Z
8	A	+Z
9	A	+X

Note: Strain gages 1 through 4 were installed normal to the X-Z plane.

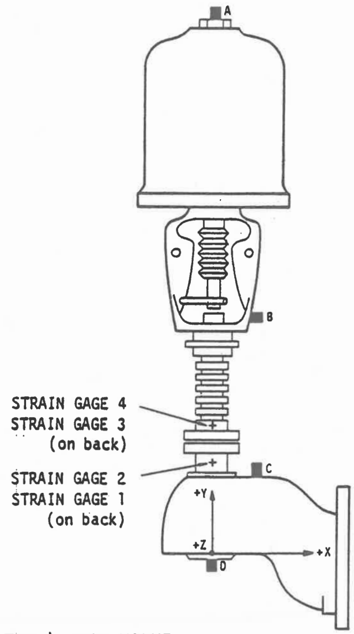


FIGURE 1. INSTRUMENTATION TEST SET-UP FOR THE 4-INCH VALVE

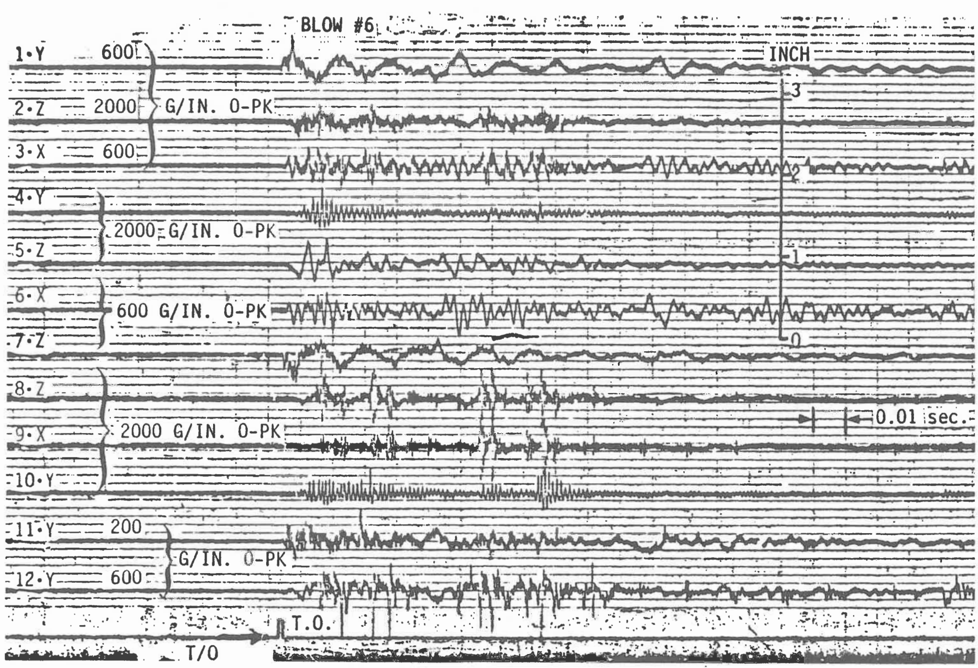
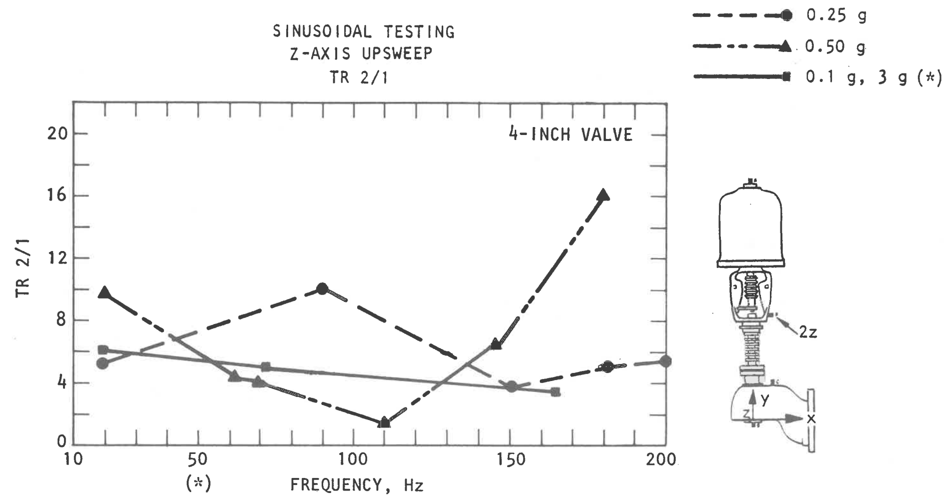


FIGURE 2. RESPONSE TIME HISTORIES UNDER SHOCK EXCITATION



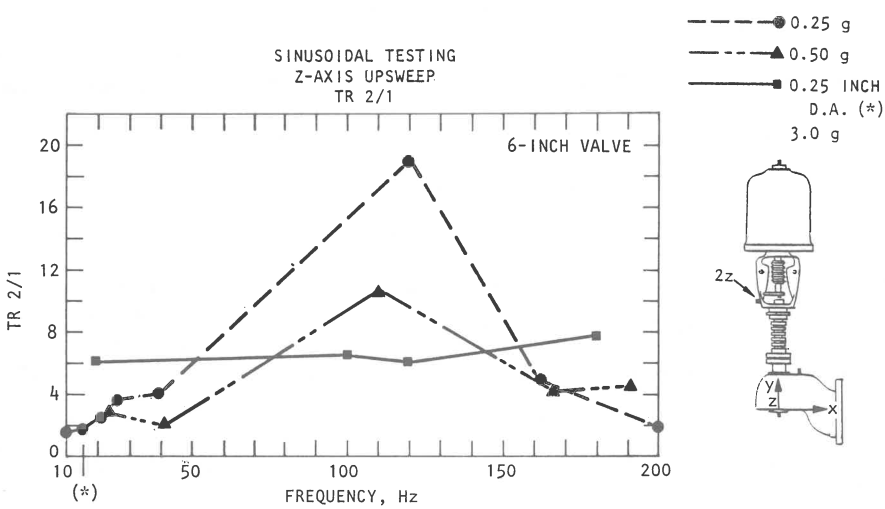
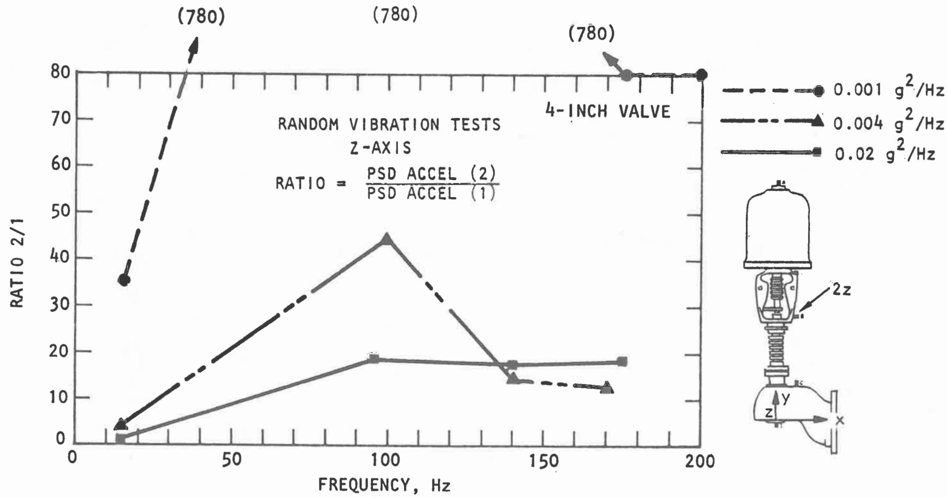


FIGURE 3. SINUSOIDAL TESTING, Z-AXIS



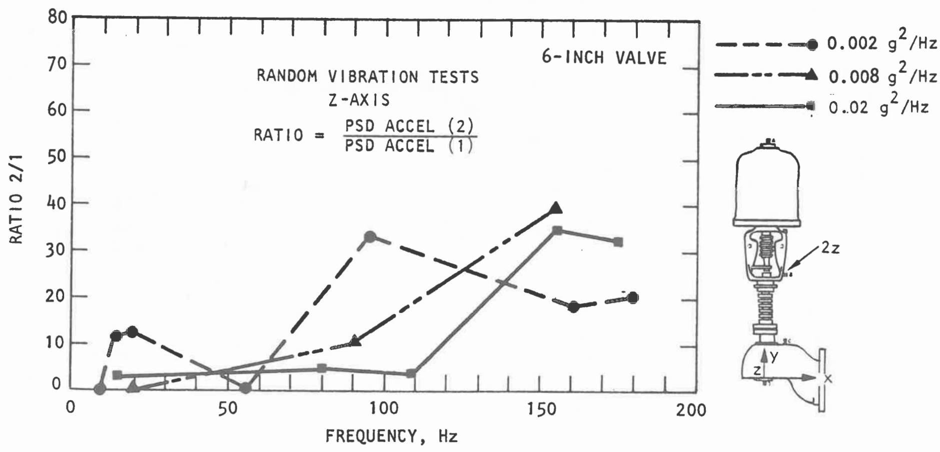
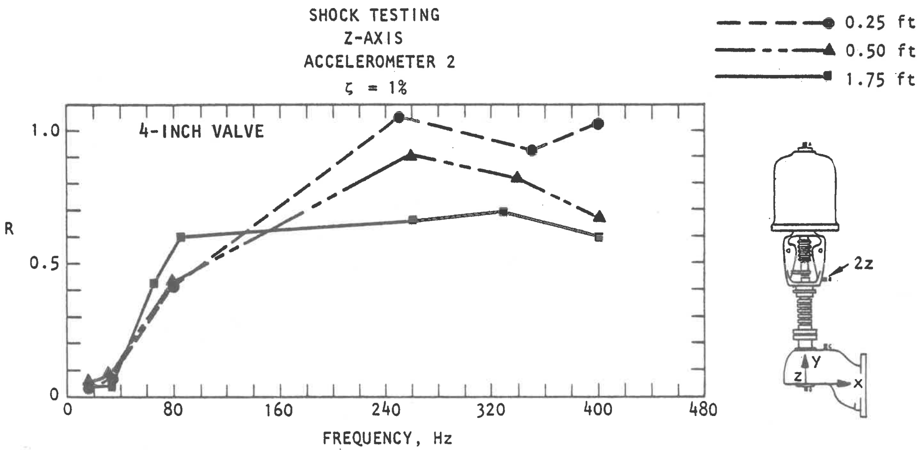


FIGURE 4. RANDOM TESTING, Z-AXIS



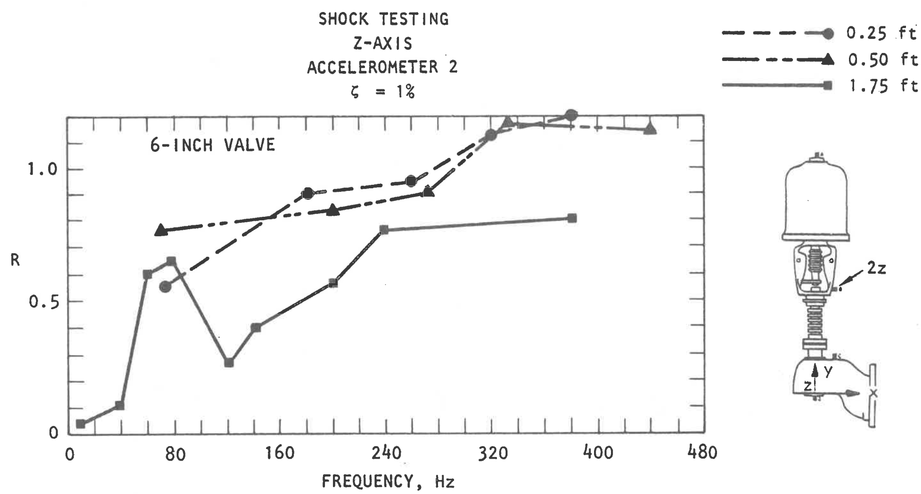


FIGURE 5. SHOCK TESTING, Z-AXIS