Seismic Analysis of Instrumentation Straight Type Manifold for Seismic Loading Conditions

Aditya M. Mashankar, Deepak S. Watvisave, Tansen Chaudhari

[1]*Abstract*— **The response spectrum method is used to measure the response of a component or equipment by analyzing the time-history of the equipment under seismic loading. The time-history of the component is measured by plotting the acceleration against the frequency of the vibration observed. It helps in understanding the peak response observed by the component. The authors have numerically demonstrated the response spectrum analysis of a straight type manifold using simulation software. This paper gives an understanding of the criterion to be decided for the OBE and SSE earthquakes.**

Index Terms— **Earthquake Response, Response Spectrum , Seismic Analysis**

I. Introduction

Seismic analysis is essential to be carried out for components, especially for the components which are to be installed in the nuclear power plants, to understand and determine their failure for three axial vibration loading. In the event of any earthquake, the components behave as a single degree of freedom system hence, the response spectrum can be obtained for any frequency. This method is more effective and accurate than the equivalent static structural method as it involves only a narrow band of frequencies and accelerations. For a given damping ratio the response spectrum is the locus of the maximum response obtained on the time history graph. The modal analysis is required to identify various modes for the given frequencies and the maximum response from the modes is combined to form the total response. For every frequency a mode shape is obtained, which gives the corresponding deformation of the component

II. Seismic Analysis - A Brief Introduction

The seismic analysis is the branch of science that deals with the vibration analysis of the components and structures. It includes the analysis of the components in static and dynamic state. The earthquake is an event which generates large amount of strain energy in the ground accelerations. These accelerations transmit vibrations to the components and equipments, for example in a nuclear power plant. The valve will be tested under static and dynamic conditions for the natural frequency up to 33hz. The static state means the vibration testing of the component for initial boundary conditions of loads and pressure. The displacement of the valve under such base excitations are essential to be calculated to understand the strength of materials used for its manufacture. With the unpredictability of the occurrences of the earthquakes and the recent earthquakes exceeding magnitudes of 7.5, it has become mandatory to analyze the components for excitation frequencies of 33Hz to 100 Hz.

III. Response Spectrum Method: A Brief Overview

During the event of an earthquake, the components and equipments behave as a single degree of freedom system. The general response obtained from an earthquake is shown below.

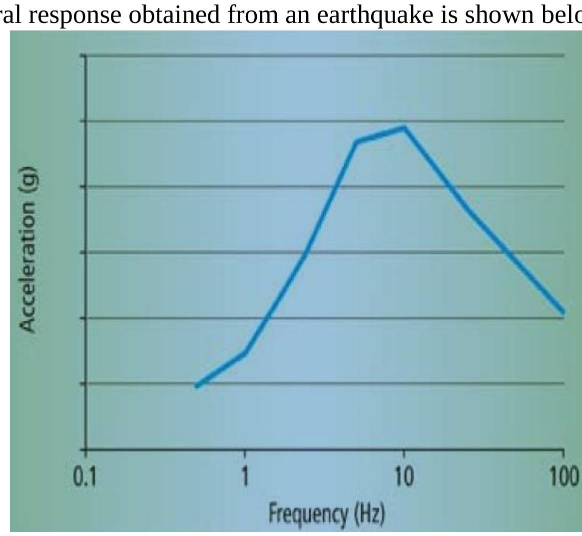

Fig 1. General response spectrum of an earthquake

The response of every periodic or non-periodic input function is divided into steady-state and transient response. If the input used is steady-state periodic then steady-state response is recorded. If the input used is transient then the peak response is recorded. Some amount of damping is essential or else the response will be infinite. To understand the concept of response spectrum, let us consider a frame undergoing

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deformation by an external force. The frame is fixed to the ground. It is diagrammatically shown below.

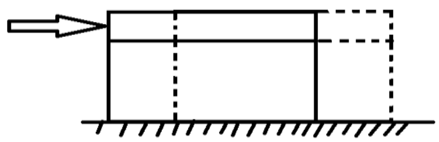


Fig 2. Earthquake response of a SDOF system

Let $\ddot{u}_g$ be the acceleration of the ground motion.

$$u_t = u + u_g \quad (1)$$

$$\dot{u}_t = \dot{u} + \dot{u}_g \quad (2)$$

$$\ddot{u}_t = \ddot{u} + \ddot{u}_g \quad (3)$$

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g \quad (4)$$

$$\text{or} \quad m\ddot{u}_t + c\dot{u}_t + ku_t = ku_g + c\dot{u}_g \quad (5)$$

We use the eqn (1) to calculate the equivalent static force ku(t) of the earthquake.

Hence the response of the system is given as

$$u(t) = -\frac{1}{\omega_D}\int_0^t \ddot{u}_g(\tau)\, e^{-\zeta\omega_D(t-\tau)} \sin\omega_D(t-\tau)\, d\tau \quad (6)$$

For a damped system i.e (ζ=0)

$$u(t) = -\frac{1}{\omega}\int_0^t \ddot{u}_g(\tau) \sin\omega(t-\tau)\, d\tau \quad (7)$$

$$u(t) = -\frac{1}{\omega}\int_0^t \ddot{u}_g(\tau) \cos\omega\tau \sin\omega t\, d\tau + \int_0^t \ddot{u}_g(\tau) \sin\omega t \cos\omega\tau\, d\tau \quad (8)$$

Hence,

$$\dot{u}(t) = \int_0^t \ddot{u}_g(\tau) \cos\omega(t-\tau)\, d\tau \quad (9)$$

$$\ddot{u}(t) = \omega \int_0^t \ddot{u}_g(\tau) \sin\omega(t-\tau)\, d\tau \quad (10)$$

The above equation gives the maximum acceleration of the response spectra.

$U_{max} = S_d(\omega , \zeta)$ gives the deformation response spectra, while

$\ddot{u}_g(t) = S_d(T , \zeta)$ gives the acceleration time history of the response spectra.

This means that spectral displacement depends on the time period and damping ratio. There are two cases depending on the flexibility of the component.

i) If the structure is very flexible, $\omega \rightarrow 0$ and $T \rightarrow \infty$

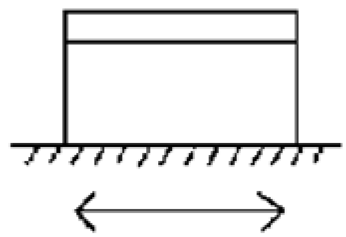


Fig 3. Extremely flexible structure

In this case, Peak deformation= Peak ground acceleration

ii) If the structure is very rigid, $\omega \rightarrow \infty$ and $T \rightarrow 0$. The excitation frequency of the structure is very high and it exceeds its natural frequency by a large margin.

IV. Literature Review

The linear response spectrum can be easily measured by established methods like the square-root-of-the-sum-of-squares method. But such methods measure only the linear response of the structure or equipment. Wong[1] has established a method to measure the non-linear response using the theory of modal analysis. Often the material and geometric non-linearities are ignored for eg. joints, the superposition principle is used to take into account these non-linearities. The force analogy method is used by the author to measure the non-linear response spectrum. The operation of a nuclear power plant in the event of an earthquake can be determined by OBE exceedence criterion. If the ground motion experienced at the plant site does not exceed that level, the plant can continue to operate. The OBE is characterized by the peak ground acceleration. This acceleration is related with the frequency of the associated vibrations and a response spectrum is obtained. Kassawara[2] has summarized an approach to develop the response of an earthquake which may affect the nuclear power plant. The conditions under which the
OBE is considered to have exceeded has been presented in this paper. The damage to the valves under varying base excitations can lead to fatigue. The variable loading conditions and dynamic loading are the main causes of fatigue. In this paper, the authors Bracsesi[3], Tomassini[3] et.al have developed method for finite element analysis calculation to determine the fatigue in the mechanical components. The dynamic behavior of the component can be expressed in the linearized form as the state-space model where the inputs were various parameters and the outputs were the modal coordinates of the component. The system was modeled within a multi-body code and the components have been modeled using

modal approach. This analysis helps in the determination of non-linear behaviors exhibited by the random seismic loading.

V. Introduction to Manifold

A manifold is block which is used to give direction and control the flow rate of a fluid passing through it, for single or multiple input/s and output/s. A manifold is a system which regulates fluid flow between pumps and actuators. The configuration of manifold valve includes block and bleed , Two-valve and Three-valve and Five-valve type. The Three-valve manifold is used as a differential pressure transmitter. It typically consists of 2 block valves and an equalizer valve. The typical working of the Three-valve manifold is shown below.

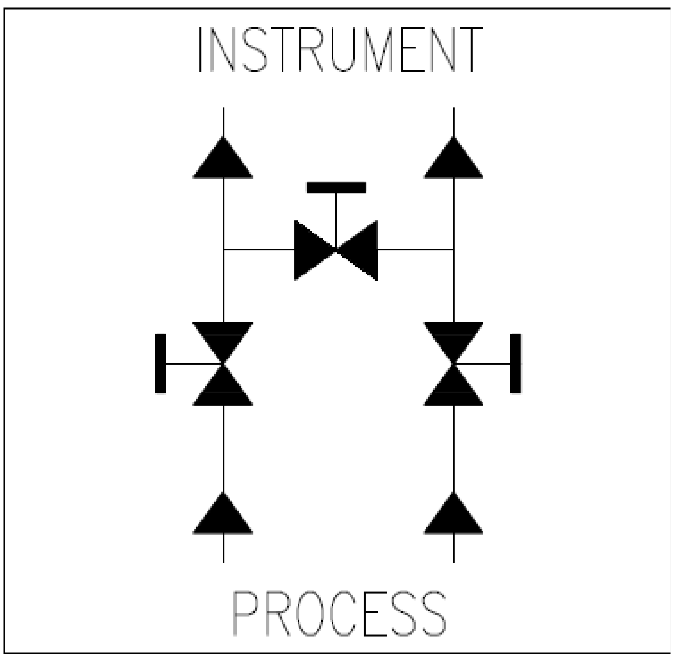


Fig 4. Typical working of Three-valve Manifold

In the above figure, the two block valves are high pressure(HP) and low pressure(LP). As it is also evident that the high pressure fluid flows through the HP block valve. The equalizer valve is used to monitor the flow rate through the manifold. The signal is sent to the actuator.

VI. Numerical Analysis of the manifold

The numerical analysis is carried out using Ansys 15.0 simulation software. The manifold is given the initial boundary conditions and pressure to analyze its behaviour under certain conditions.

i) <u>Boundary Conditions</u> - Initial boundary conditions are given in the Static Structural analysis to calculate the total deformation and the equivalent stresses and strains of the manifold. The manifold is fixed at the T-side holes and a ramped input of 0.9414 MPa is given at the entry ports. The results are obtained for total deformation, equivalent static strain and equivalent static stress. The static structural analysis is essential to check the manifold for various input conditions which include varying pressure and force conditions. This helps in analysing the component for various working environments. An efficient meshing is required to obtain accurate results such that the pressure conditions can be determined precisely.

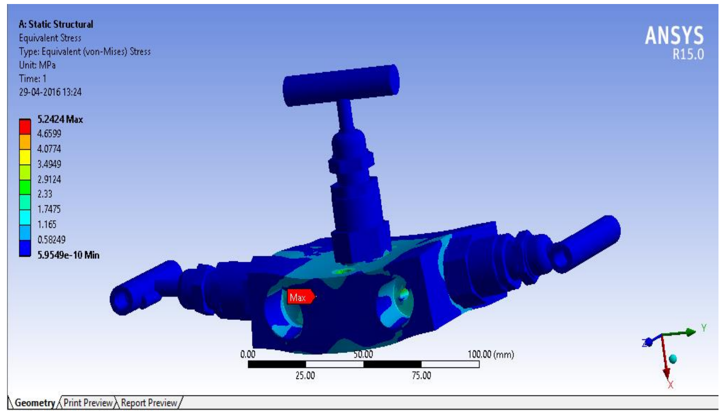
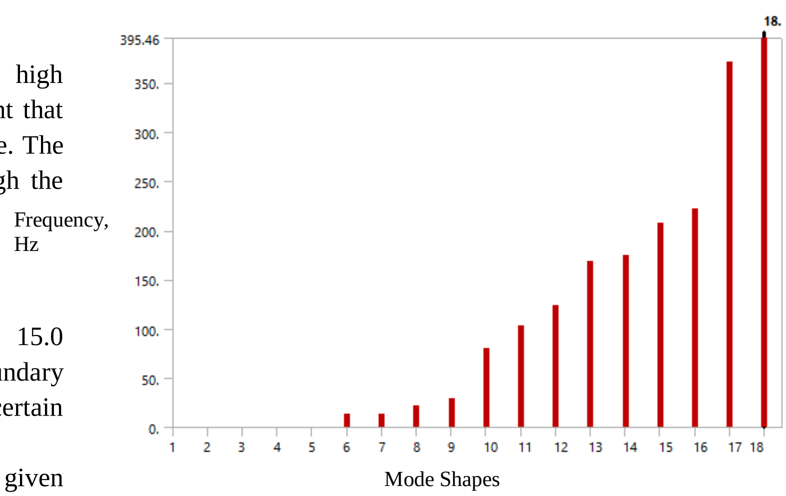
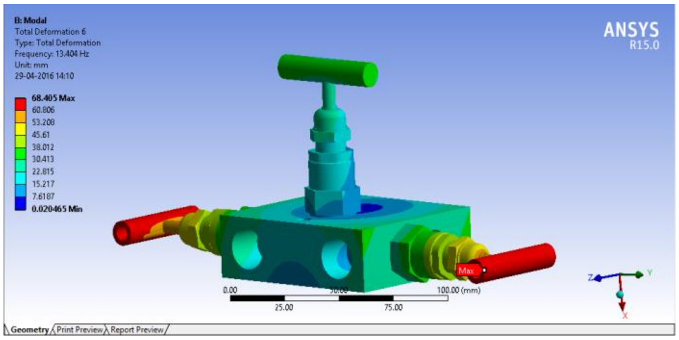


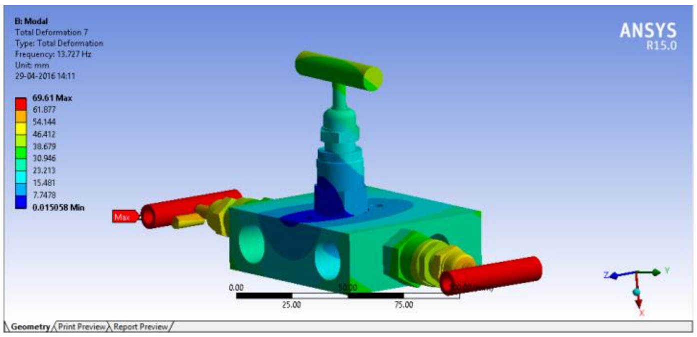
Fig 5. Equivalent static stress

ii) <u>Modal Analysis</u> - It is carried out to calculate the mode shapes of the component at various frequencies. They are the Eigen vectors of the mathematical equations. The frequencies are denoted as Eigen values of the matrix equations. In this analysis 18 modes are calculated for corresponding frequencies. The first six modes are essential for determining the frequency response of the component. The purpose of modal analysis is to determine the modal displacement of the component for the corresponding excitation frequencies during the entire cycle of vibration loading. It is shown in graphical form below.





6 th Mode



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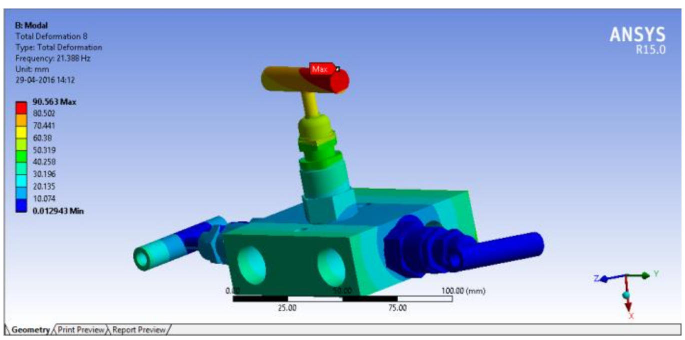

8 th Mode

The above figures indicate the modal response of the manifold for three different frequencies. The corresponding mode shapes of the manifold are obtained at the frequencies of 68,69.05 and 90.56 Hz, which are considered for modal analysis.

VII Future Scope

The experimentation of the manifold will be carried out on Horizontal and vertical shake table to determine the amplitude for corresponding frequency of vibration. Helium leak test will also be conducted in pressurized condition to determine leakage in the manifold.

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