Dynamic Analysis of THRR-20 Internals

YU Su-yuan[1)], ZHANG Xiao-hang, LI Da-wei, WU Hong-lin, HE Shu-yan

1) Institute of Nuclear Energy Technology, Tsinghua University, Beijing, 100084,China

ABSTRACT

Tsinghua 20MW Research Reactor （THRR-20） is a pool-type reactor, with a compact core-design. The internals consist of the heavy water tank, support plate, inner support cylinder, and outer support cylinder as well as the core. A 3D finite element model which considered both the spatial arrangement and the reactor components shapes was used for the modal analysis and the response spectrum analysis to calculate the modal results and response stresses, the displacements, etc. for the seismic load. The analysis results indicate that the reactor internals have enough strength for the expected seismic load and the stresses and displacements satisfy the reactor safety requirements.

INTRODUCTION

Along with the development of nuclear technology, research reactors have been developed as very important research tools in fields such as physics, chemistry, biology, material science, etc. for advanced multi-disciplinary research. Among these multi-disciplinary projects, fundamental research using neutron beams have been widely used in the fields of environment science, life science and material science in recent years [1]. According to IAEA, a total of more than 500 research reactors, including over 300 operating piles, are scattered in about 70 countries of the world [2]. Recently, the development of the new fuel U3Si2-A1 [3] has resulted in new research reactors using inverse neutron trap principle and compact core-design, for example, IRT-1 of Libya, RSG-GAS-30 of Indonesia and ORPHEE of France. In these reactors, not only have high fast or thermal neutron fluxes, but also can supply space for neutron flux division. The Tsinghua 20MW Research Reactor （THRR-20） is one such reactors which has adopted these advanced technologies. It is a pool-type reactor using light water as the moderator and coolant and Be and heavy water as the reflector.

The Tsinghua 20MW Research Reactor internals, including the heavy water tank, support plate, inner support cylinder, and outer support cylinder as well as the core are the key equipments in the reactor, so the dynamics properties of these internals directly influences the operational safety of the core and the whole reactor. If the internals are disrupted or destroyed, radioactive material would flow out of the reactor polluting the environment with serious results. Therefore, to ensure operation of safety, the structural dynamics of the internals were analyzed with FEM to evaluate their safety.

STRUCTURE AND FINITE ELEMENT MODEL OF INTERNALS

The Tsinghua 20MW Research Reactor consists of the reactor body, internal supports and other structures. The reactor body includes the core, the heavy water tank, the reflector, etc. The internal supports include the support plate, the inner support cylinder, the outer support cylinder, etc. The vertical section of the reactor structure is shown in fig. 1. The heavy water tank is cylindrical on the outside （ϕ2000mm$\times$20mm）and square on the inside （699.8mm$\times$623.6mm）with a height of 1600mm and is filled with heavy water as the core reflector. The support plate is a circular flat-plate ϕ970mm and 80mm thick which supports and locates the core. The inner support cylinder ϕ970mm by 20mm thick and 1500mm high supports the weight of the support plate and the core. The outer support cylinder ϕ2000mm by 20mm thick and 1500mm high supports the heavy water tank and the heavy water. The support plate material is Aluminum-alloy 6061 while the other structures use Aluminum -alloy 5052. NASTRAN 2000, MSC, U.S.A., was used to analyze the internal dynamics. NASTRAN 2000 is a large, general-purpose tool for FE analysis which reflects the latest technologies for structural dynamics analysis at the end of 90's. NASTRAN 2000 is a powerful tool for FEM analysis and design [4]. A 3D finite element model was built using the actual shapes and positions of the internals with eight node shell elements to model the thin-wall structures, girder elements to model the reinforcing ribbed plate structure and rod elements to model the hinged support structure. The core can be simply modeled as a rigid rod because its fundamental frequency of 110Hz is far more than the 33Hz of the seismic load. The water in the closed space between adjacent components was modeled as part of the mass of the fuel components. The water in the inner support cylinder, the water between the inner and outer support cylinders and the water outside of the outer support cylinder were all modeled as supplemental masses directly loaded on the related vessels.

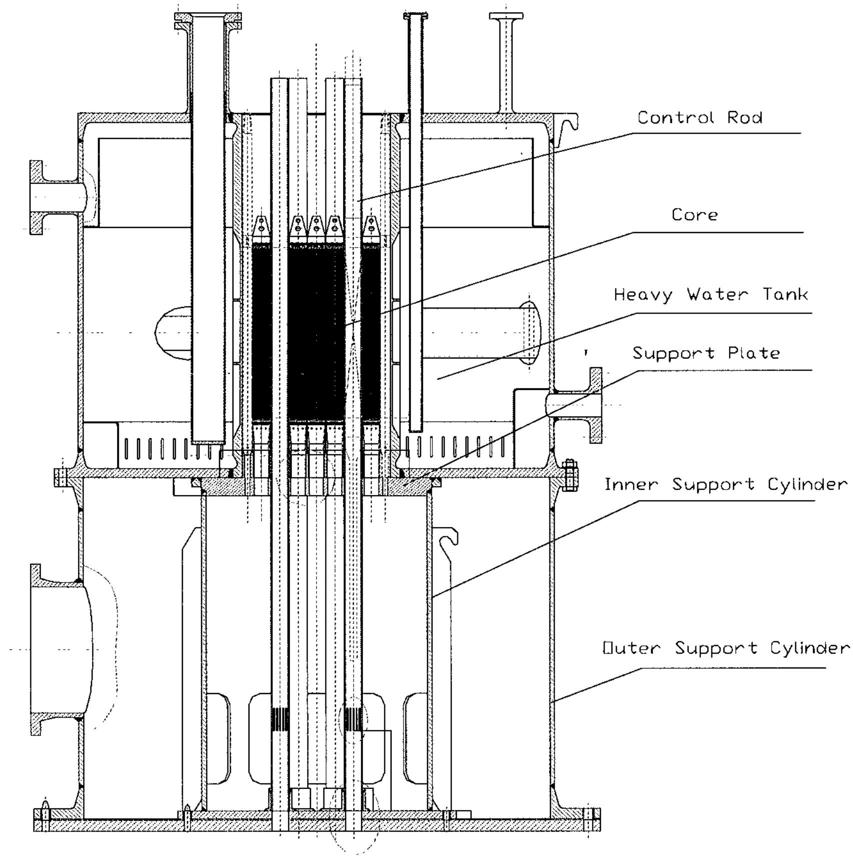

Fig. 1 THRR-20 internals

MODAL ANALYSIS OF INTERNALS

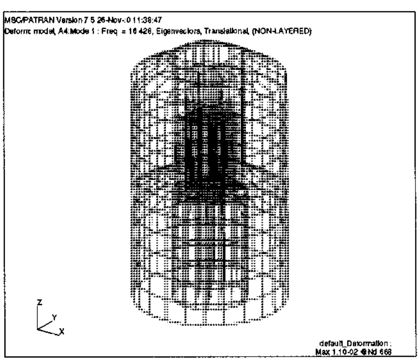

Fig. 2 Vibration mode 1 while the vessel is being filled

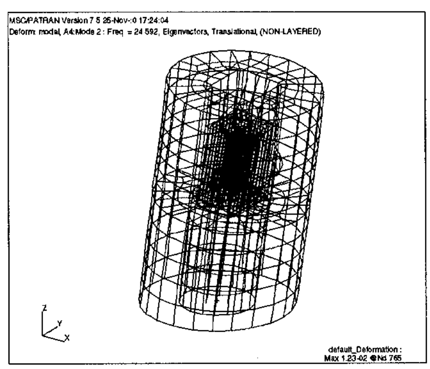

Fig. 3 Vibration mode 2 while the vessel is being filled

The modal analysis is used to calculate the inherent frequency and vibration mode of the internals. The interaction between the internals and the supports can then be evaluated for further dynamics analysis and the main vibration modes can also be determined to calculate the responses of the entire structure. Fig. 2 and Fig. 3 show the first order and second order vibration modes of the internals while the vessel is being filled with water. Table 1 lists the main vibration modes and the related frequencies for each order.

The results show that the basic frequency is 16.24Hz which is out of the peak range of the floor spectrum acceleration

(8~13Hz). The main vibration modes are concentrated in the heavy water tank. The first order vibration mode is vibration of the heavy water tank along the Z axis (vertical) due to the support mode of the heavy water tank. The second and third order vibration modes are pendulum motions of the reactor body along the X and Y axis (along the central line of the inside square in the heavy water tank) with frequencies between 24Hz and 25Hz. The results indicate that square core design would affect the rigidity of the whole structure, but the rigidities in different directions are very similar. Moreover, the basic frequency of the structure without considering the water is 65.37Hz which far exceeds the frequency calculated when considering the water mass. Therefore, the dynamics property of the structure is obviously influenced by the water in the pile. In the model without considering the water, the fifth and sixth order vibration modes are torsional modes around the axis Z which shows that in the square core, torsion in the structure is quickly damped.

Table 1. Main Vibration Modes and Inherent Frequencies of the Supplemented Water Mass Model

Model	Vibration Mode	Frequency [Hz]
1	Vibration of heavy water tank along the Z axis	16.240
2	Entire vibration along the X axis	24.592
3	Entire vibration along the Y axis	24.745
4	Vibration of the internal heavy water tank wall along the X axis	35.137
5	Vibration of the internal heavy water tank wall along the X axis	39.456
6	Radial vibration of the heavy water tank outer shell (Shell Vibration Mode)	43.250
7	Radial vibration of the heavy water tank outer shell (Shell Vibration Mode)	43.294
8	Radial vibration of the heavy water tank outer shell (Shell Vibration Mode)	44.210

RESPONSE SPECTRUM ANALYSIS OF INTERNALS

The Tsinghua 20MW Research Reactor can be simplified as a multiple-degree-of-freedom system. According to the self-oscillation mode, its seismic responses can be divided into many single-degree-of-freedom systems, and the maximum responses for each system can be achieved through the responses spectrums. The dynamics analysis also used the finite element model built for the modal analysis. For SSE, the internals damping factor has a value of 0.04. The bottom of the internals is at a level of –0.75m. The inputting response spectrums (Fig. 4 ~ Fig. 6) that were obtained through seismic analysis of the plant were used to separately calculate the responses in the three directions for seismic excitation, and then the elements stresses were calculated by combining the three results.

To ASME third class equipment, load on the components from normal operation, vibration of the SSE and power system in an accident, cannot cause stresses exceeding 150 percents of the permissible stress [5].

The results show that the maximum deformation in the X direction in the enclosing board of the active region has a value of about 0.26mm; The maximum equivalent Von-Mises stress, 2.12 MPa, was located in the restrained bottom of the outer support cylinder close to the X axis. In the upper part of the plant, including the interior wall of the heavy water tank, the equivalent Von-Mises stresses during seismic load along the X direction were about 1MPa which is far below the permissible stress intensity for the material. For seismic loads along the Y direction, the maximum displacement in the Y direction in the enclosing board of the active region in the heavy water tank was 0.02mm with the equivalent Von-Mises stress in the outer support cylinder close to its bottom of 2.5MPa. For other points, the integral level of stress is of the same order of magnitude as 1MPa, far below the material yield stress. In the Z direction, the interior wall of the heavy water tank is only restrained by the upper and the lower tank support plates, so its maximum displacement was 0.3mm and the equivalent Von-Mises stress was 4.3MPa at the angular points where the upper and the lower plates are joined to the tank. These points are the weakest link and should be carefully welded and inspected.

The stresses in the three directions and the static analysis stress were combined to get the total stress in the internals as table 2 shows. As the results indicate, the maximum tress is in the enclosing board of the heavy water tank and the maximum equivalent Von-Mises stress is 42.0MPa. Since the permissible stress is 63.75MPa, then the reactor internals have enough strength to satisfy the safety requirements for the expected seismic loads.

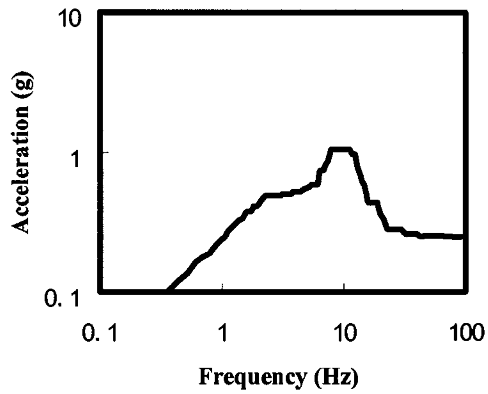

Fig. 4 Seismic response spectrum along X axis

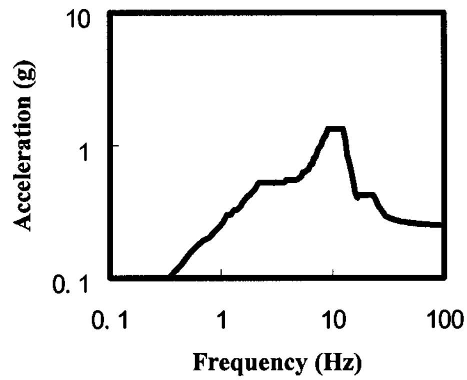

Fig. 5 Seismic response spectrum along Y axis

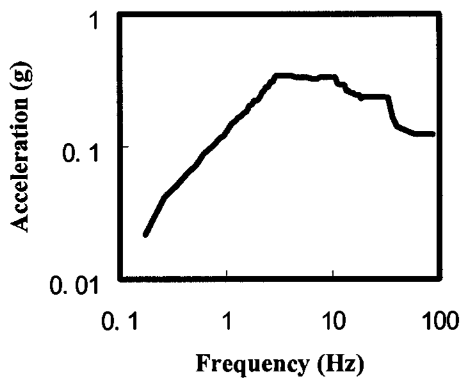

Fig. 6 Seismic response spectrum along Z axis

Table 2 Maximum Equivalent Von-Mises Stresses [Unit: MPa]

	Inner Support Cylinder	Outer Support Cylinder	Support Plate	Heavy Water Tank (enclosing board)
Maximum Equivalent Von-Mises Stress	6.0	5.3	24.0	42.0

CONCLUSION

The vibration modes in the Tsinghua 20MW Research Reactor internals due to seismic excitation are in the longitudinal direction (first order mode) and the horizontal direction (second and third modes), with these main modes concentrated in the heavy water tank. The first order mode is vertical vibration of the tank mostly due to the tank support structure which completely supports the tank by the outer support cylinder using a flange to restrain the outer edge of the tank with no restraint added to the inner square surface. Pendulum motion of the interior wall of the tank along the horizontal symmetry axis has a frequency low than 40 Hz and is mainly in the active region. The basic frequency of the dynamic response is 16 Hz which is above the range of the floor spectrum acceleration (8~13Hz). Therefore, the structural design has a good dynamics property.

If the structures are analyzed without the water mass, the basic frequency is 65.37Hz, far higher than when water mass is added to the mass of internals. Therefore, the internal water greatly influences the entire dynamics property of the reactor.

The response spectrum analysis indicated that the internal maximum stress due to the seismic load was far below the permissible stress; therefore, the internals have sufficient safety margins.

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