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Modal Analysis of Spent Fuel Cask for WWER-1000 Reactors

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Abstract: The Spent Fuel Assemblies (SFAs) of WWER-1000 reactors are planned to be transported by special containers which are supposed to be designed in a manner to stand against vibrations and impacts in order to protect the spent fuel from any possible damage. The vibration opposition of these containers shall be far beyond the critical resonance, because the resonances about the natural frequency of the structure will cause the enhancement of its oscillation range and may end with its disintegration. Determination of the amounts of natural frequencies and their mode shape can be achieved by vibration analyzing methods. The amount of the natural frequency of any structure crucially depends on its shape, material and lean points as well as the amount of the loads and the type of these loads. Due to the fact that the Spent Fuel Casks used for transportation in nuclear power plants in Russian Federation are TK-13 type and the pieces of information released are negligible, the scientists in Russia are working on the design and analysis of a new type made up of composite Material. In the presented paper the cask of spent fuel of TK-13 is modeled by ANSYS® 10.0 and ten natural frequency modes have been calculated, followed by the comparison of this result with the composite cask.

Keywords: ***Natural Frequency, Vibration Mode, WWER-1000 Reactor, Critical Resonance, Spent Fuel Transportation Cask, Composite***

1- Introduction

The modal analyses are performed to determine the vibration characteristics of structures. The main purpose of modal analysis is to determine the natural frequencies and mode shapes of the spent fuel transportation of a cask. The natural frequencies and mode shapes are important parameters in the design of a cask for dynamic analysis such as harmonic response or transient analysis. The TK13 cask is an updated variant of TK12 meeting the requirements of "the basic safety and physical protection regulations related to shipment of nuclear materials (OPBZ-83)" and the "regulations for the safe transportation of radioactive materials" (the IAEA Regulations-85/90)". In other words, the body and lids were strengthened in such a manner that the spent fuel cask could withstand a rigid barrier impact test carried out at the velocity not less than 90 m/sec. The modal analysis of spent fuel cask with ANSYS®10.0 products is a linear analysis. Furthermore, ANSYS®10.0 software is used to determine the system response resulting from a harmonic excitation. Any nonlinearity such as plasticity and contact (gap) elements, are ignored even if they are defined [1].

2- Specification of Spent Fuel CASK (TK-13)

The Spent Fuel Assemblies (SFAs) of WWER-1000 reactors are planned to be transported by (TK-13) casks. Each spent fuel transportation cask holds 12 spent FAs and has a thick steel container to provide shielding. The transportation of the spent fuel cask is shown in Fig. 1 that indicates the spent FAs discharge into cask (TK-13). The calculations are made for SFAs with burn ups of 60 MWd/kg and 3-year cooling period. The ANSYS®10.0 general finite element analysis package is selected for this analysis, since it is an analytical tool widely used for licensing to spend nuclear fuel casks. The selected model includes all significant heat transfer paths within the cask and between the cask and the external environment. Two cases are considered: Dry Container and a Container Filled with Water Without Boron. Table. 1 shows some specifications of the Cask (TK-13) [1, 2 and 3].

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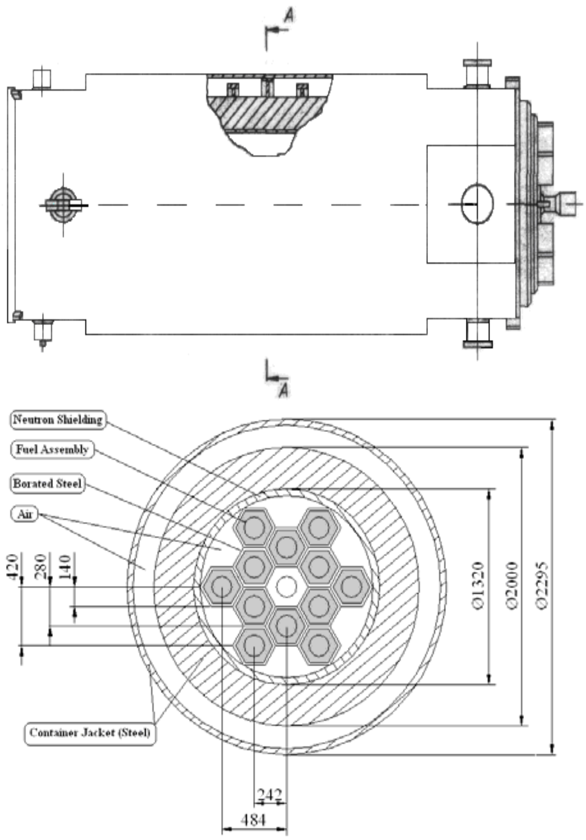


Fig. 1. The(TK-13) cask for spent fuel transportation.

Table. 1. The characteristics of the spent fuel cask (TK-13)

Characteristics of SFA CASK (for WWER-1000 reactors)	VALUE
Number of SFA	12
Weight of empty cask	100 tons
Weight of uranium (average) - One fresh fuel assembly - One spent fuel assembly - Total of 12 spent fuel assembly	431.6 (kg) 416.0 (kg) 5000 (kg)
Height of cask (dimensions)	6000 (mm)
External diameter of cask (container jacket)	2295 (mm)
Diameter of internal cavity	1225 (mm)
Thickness of steel that surround the cask	340 (mm)
Initial enrichment in U^{235} of cask	%5 or less
Mean depth of fuel burnout	40 Mwatt. day/kgU
Maximum depth of fuel burnout	60 Mwatt. day/kgU or less
Time of holding in reservoir	3 Year

3- Material Properties of Cask (TK-13)

The mechanical characteristics of the cask, the structural materials and the simplified SFA model used in calculations are given in Table. 2 The parameters of SFAs are selected on the base of the estimates of the strained state of the fragment of spent fuel element bundle subjected to bending and the results are obtained from testing the fragment of spent fuel element bundle [4].

3.1 Modeling of Spent Fuel Cask (TK-13)

The computer model is developed to estimate the frequency spectrum of the cask, its stress-strain state, as well as the vibration strength of one single or an array of cask to be transported by truck, railway and/or by airplane. The computer model of cask involves a detailed computer model of (TK-13) cask and a simplified SFAs model. All spent fuel cask (TK-13) components are presented in the computer model mathematically in detail. This makes it possible to determine the cask frequency spectrum with rather good accuracy and to describe the cask deformation under vibration loads as a 3D process. The computer model of SFAs used in calculations represents a solid body having the dimensional and mass characteristics similar to those of real SFAs. This SFAs model makes it possible to determine fairly correctly the natural frequencies of the spent fuel cask and to describe the interaction between the cask and SFAs under the vibration loads. The computer model of the spent fuel cask in ANSYS®10.0 software is shown in Fig. 2.

Table. 2. Material properties of the spent fuel cask

Component	Material	Modulus of elasticity E_x (Gpa)	Material density $\rho (g/cm^3)$	Poisson's ratio ν
Spent fuel cask	Steel 10	210	7.8	0.3
Bolts	Steel 3	210	7.8	0.3
FA	-------	8.72	3.56	0.3

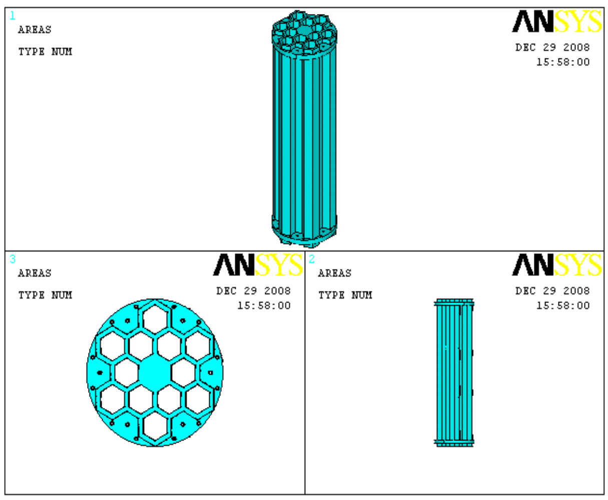


Fig. 2. Computer model of spent fuel cask in ANSYS®10.0 software.

3.2 Meshing of Spent Fuel Cask (TK-13)

The 3D element used for modal and vibration analysis in ANSYS®10.0 software is SOLID95, which is often used for structural analysis. It can tolerate irregular shapes with negligible loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element may have any spatial orientation. The geometry, node locations, and the coordinate system for this element are shown in Fig. 3. With respect to the type of analyses, suitable elements were selected and the computer model of the spent fuel transportation cask was meshed in ANSYS®10.0 software. The meshing of the model is shown in Fig. 4 [2].

3.3 Boundary Conditions

The free stress method was used in vibration analysis of the spent fuel transportation with the cask. According to the model of the cask, all nodes and elements on A1 and A2 surfaces of the spent fuel transportation cask model in all three direction, (X,Y,Z) are assumed to be constant. The weight parameter is also used in these analyses. The real constants used in this study are:

- Environmental conditions such as inner and outer temperatures of the cask [5]
- Gravity
- Atmospherc pressure (760mmHg) 103.3 Kpa and any other parameters needed for the vibration analysis [2].

4. Results

In order to perform the vibration analysis of the spent fuel cask, the computer model and other requirements needed for ANSYS®10.0 software, have been defined. Some examples of the analysis results of the model are given in this section, along with some explanations. The first to ten modes of natural frequency of the spent fuel transportation are given in Table.3 and the sixth result of the vibration analysis of the spent fuel transportation with the cask is given in Table. 4. The amount of the total displacement of the spent fuel transportation in the first, second to tenth vibration modes are shown in Fig. 5.

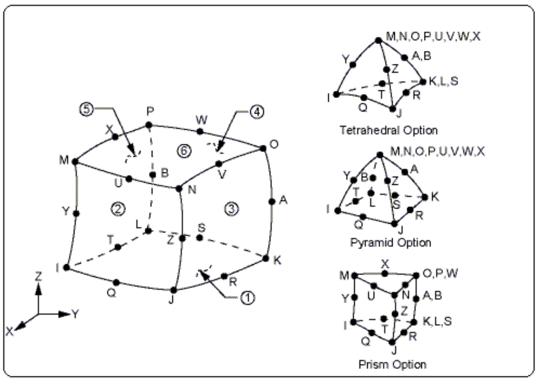


Fig. 3. Shape, geometry and dimension of SOLID95 element.

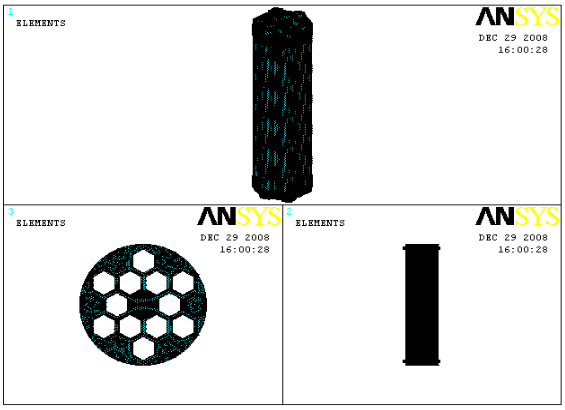


Fig. 4. Meshing the model of SFAs in ANSYS®10.0 software.

Table. 3. The first ten mode of Natural frequency of the cask

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.18694	1	1	1
2	0.18702	1	2	2
3	0.27860	1	3	3
4	0.41364	1	4	4
5	0.41380	1	5	5
6	0.45202	1	6	6
7	0.55594	1	7	7
8	0.67155	1	8	8
9	0.67178	1	9	9
10	0.83152	1	10	10

Table. 4. Sixth results of the vibration analysis of spent fresh transportation with cask

Mode	Natural Frequency	Maximum, U_x / Minimum, U_x	Maximum, U_y / Minimum, U_y	Maximum, U_x / Minimum, U_x	Maximum, U_{sum}
First	0.186935	-0.399E-06	0.979E-07	0.147E-07	0.407E-06
		-0.961E-08	-0.981E-07	-0.924E-07	
Second	0.187023	0.900E-07	0.101E-06	0.397E-06	0.406E-06
		-0.175E-07	-0.101E-06	-0.102E-07	
Third	0.278596	0.604E-06	0.307E-07	0.524E-06	0.604E-06
		-0.604E-06	-0.307E-07	-0.524E-06	
Forth	0.413640	0.359E-06	0.228E-06	0.192E-06	0.393E-06
		-0.359E-06	-0.226E-06	-0.191E-06	
Fifth	0.413799	0.185E-06	0.206E-06	0.356E-06	0.398E-06
		-0.185E-06	-0.202E-06	-0.356E-06	
Sixth	0.452015	0.731E-07	0.331E-06	0.683E-07	0.331E-06
		-0.732E-07	-0.178E-07	-0.695E-07	

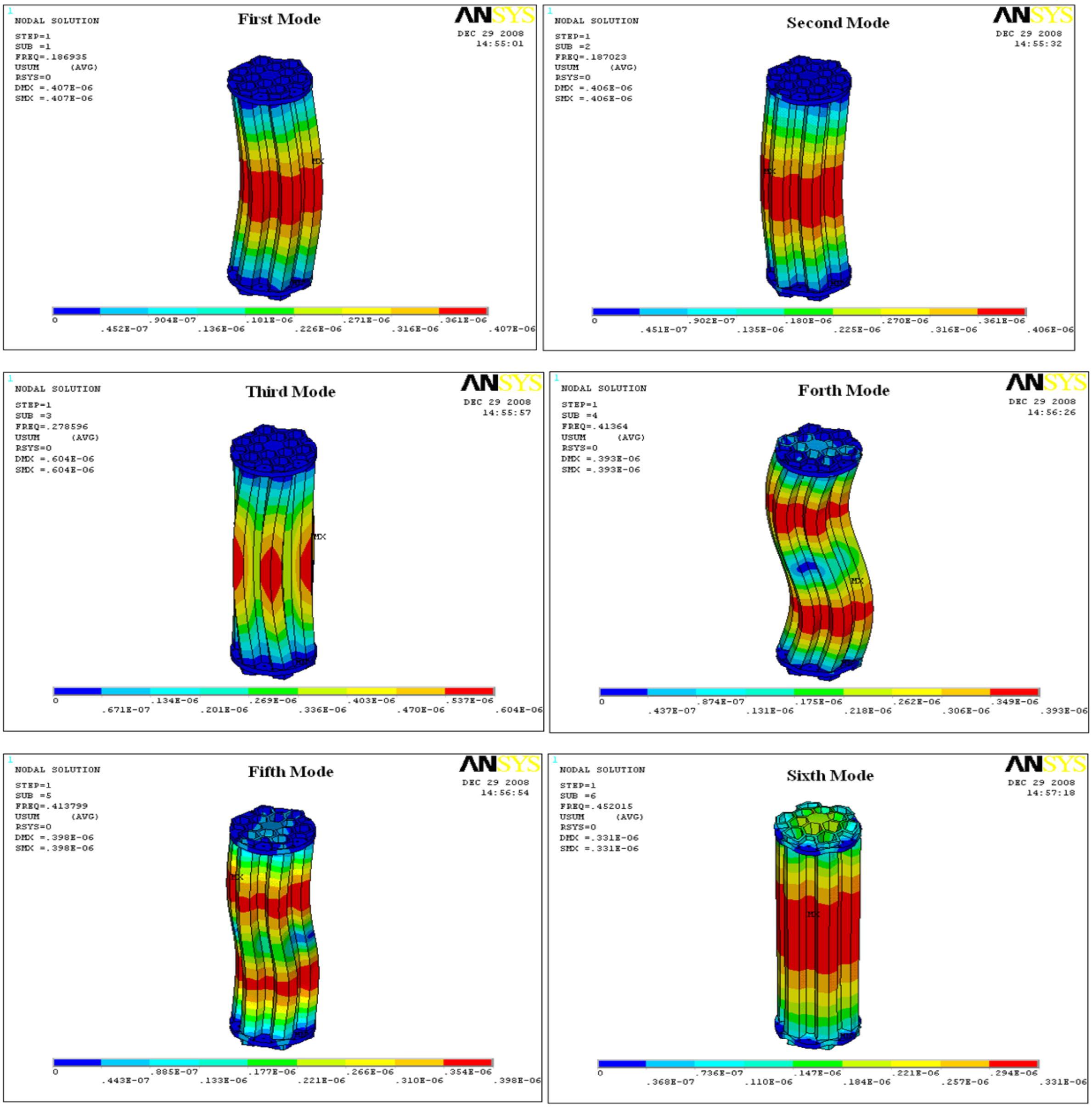
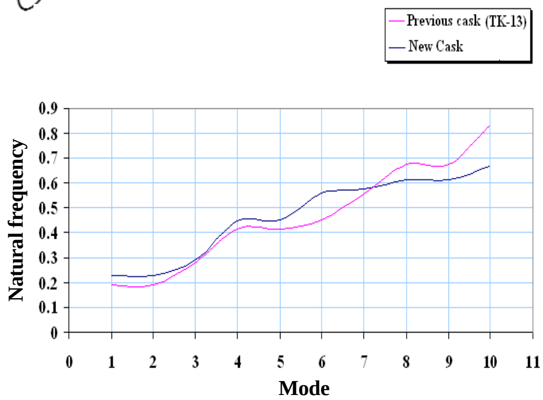


Fig. 5. Sixth modes of natural vibrations of cask.

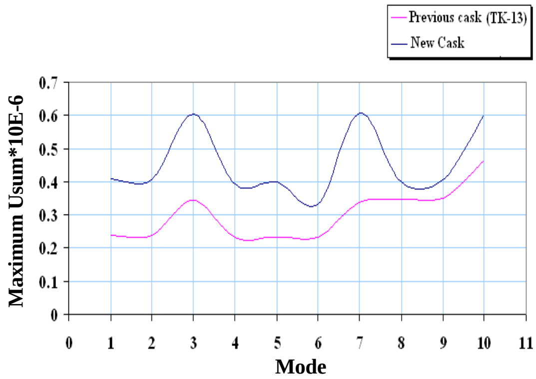
5- Conclusions and Discussion

According to the researches conducted by the Russian Federation scientists, the new type of composite Material cask could preserve 36 spent fuel assemblies [6]. The data achieved in this paper are compared with the initial data released for such a design. The results of the modal analysis for the spent fuel cask (TK-13) are compared with the initial results of the new composite spent fuel cask in Figs. 6 and 7. Comparing the results of the modal analysis of the spent fuel cask (TK-13) with the composite spent fuel cask (new cask with 36 FAs) we conclude:

- In Fig. (6.a): the natural frequency of the new cask and the previous cask (TK-13) on modes of 3 and 7 are equal.
- In Fig. (6.b): the natural frequency of the new cask between the modes of 1 and 7 is more than the previous cask (TK-13) and after mode 7 it reverses.
- In Fig. (6.b) and (7.b): there are two peaks on modes 3 and 7 for Max Usum and Uy, but the rate of the peak of the new cask is more than the previous cask (TK-13).
- In Fig. (7.a) and (7.b): there are two peaks on modes 3 and 7 for Max Ux and Uz, but the rate of the peak of the previous cask (TK-13) is more than the new cask.
- Considering the modal analysis and following it we can do dynamic analysis calculation.

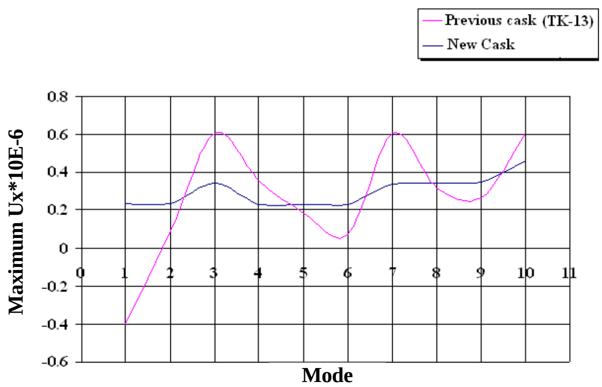


(a)

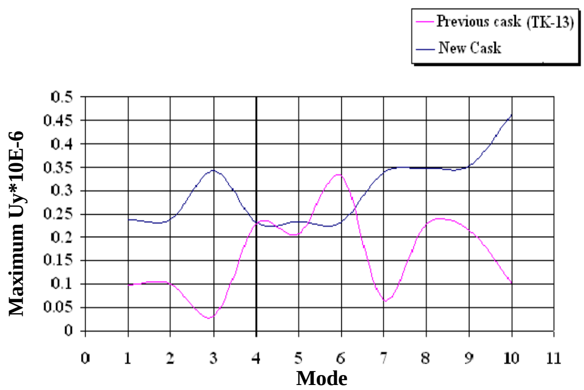


(b)

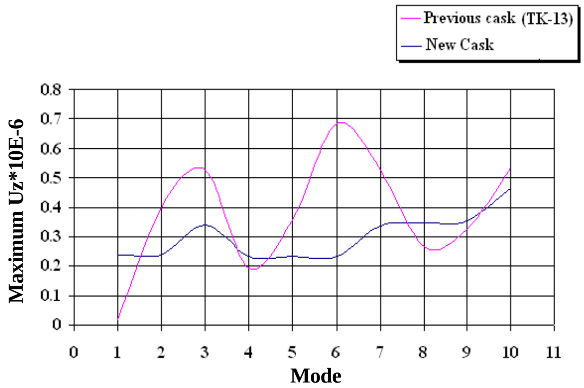
Fig. 6. Compare the results of the cask (TK-13), and composite Material spent fuel cask (new cask), numerical frequency(a), Maximum Usum (b) in 10 Modes.



(a)



(b)



(c)

Fig. 7. Compare the results of the cask (TK-13), and composite spent fuel cask (new cask), Maximum Ux, Uy, Uz in 10 Modes.

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