Modal analysis of transport complex and drop tests of container for transport of spent nuclear fuel

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Abstract: Packages for transporting radioactive materials have to meet requirement of normal and accident transport conditions. On the basis of methodology of experimental verification packages for transport of radioactive materials elaborated by authors were realized extensive tests of containers. In the paper is described modal and vibration analysis of transport complex during its transportation as well as drop and penetration tests that were accomplished on a scale-down model by using special test stand allowing positioning of container model before falling.

Keywords: transport complex, container, vibration analysis, drop tests

1. Introduction

Transport containers serve for manipulation and transport with spent nuclear fuel from reactors of nuclear power stations. During the certification of packages (containers) for transporting radioactive materials is necessary to provide analyses that they meet requirements of Regulations of Nuclear Regulatory Authority of the Slovak Republic - UJD SR No.57/2006 Z.z. for normal and failure conditions of transport [1]. On the workplace of authors was recently realized safety verification of containers by analytical and numerical methods [2]. Because of fact that above-mentioned verification recommends for the assessment of container safety experimental methods, the autors had elaborated methodology for such a test of nuclear waste packages [3,4]. One part of extensive experimental analysis [5,6,7] was a modal analysis and analysis of vibration of real transport complex during its moving as well as container drop tests realized on scale model.

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In the paper are given methods and some results of above-mentioned experimental tests.

2. Modal analysis and vibration of transport complex

According to Supplement No. 1 of Regulation No. 57/2006, Part II., the consignment have to withstand any accelerations, vibrations, or resonances that can arose under conditions presumable during normal transport without decreasing of tightness of closure mechanisms in different parts of package or without violation of its integrity. From this reason has been accomplished modal analysis and analysis of vibration of system container – wagon, during its movement with prescribed velocity, starting, breaking as well as movement through twists and locations, where mechanical vibration of system could occur [8]. Container (Fig.1) is positioned during the transport on special railway wagon (Fig.2). Selected transport conditions and technical parameters of transport complex are max. velocity of loaded coach 100 km/h, weight of container 68 t, weight of wagon 35 t, max. loading capacity of wagon 85 t.

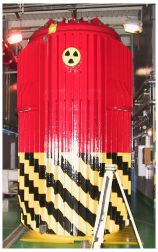


Fig. 1. Container for transport of spent nuclear fuel.

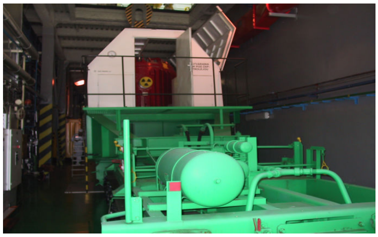


Fig. 2. Transport complex with container.

Modal analysis of carrying part of wagon bridge was realized for two positions of three-axis acceleration sensor Brüel & Kjær 4506B. Sensor S1 was positioned on a lid of container (Fig.3a) and sensor S2 on a frame of undercarriage above pan of wagon bearing (Fig.3b). Locations of sensors allow gaining information about transmission of vibration excitation during movement of complex.

a) b)

Fig. 3. a) location of sensor S1 on the lid of container, b) location of sensor S2 on the frame of undercarriage above bearing shell of wagon.

The locations of hammer impact were chosen in such a way that the longitudinal and transversal symmetry of wagon has been exploited. There were chosen 9 locations for excitation by impact hammer. The locations were the same for both sensors (S1 and S2). Acceleration sensors S1 and S2 had axis x in vertical direction, axis y was oriented perpendicular to axis of wagon and axis z was identical with wagon's axis. Functions of frequency transfer measured for individual positions of excitation were processed in program Pulse Reflex. Software algorithms using function CMIF (Complex Mode Indicator Function) has been used for estimation of eigenshapes and eigenfrequencies. The eigenfrequencies determined by this procedure on the basis of analysis of stability diagrams are given in Fig.4. It represents AutoMac matrix of eigenshapes.

	4.326	13.992	35.365	44.366	74.145	81.370	98.544	120.197	435.889	696.708
4.326	1.000	0.671	0.228	0.687	0.626	0.503	0.768	0.900	0.751	0.878
13.992	0.671	1.000	0.726	0.677	0.282	0.807	0.768	0.769	0.628	0.711
35.365	0.228	0.726	1.000	0.420	0.089	0.757	0.384	0.351	0.257	0.292
44.366	0.687	0.677	0.420	1.000	0.367	0.499	0.701	0.630	0.495	0.639
74.145	0.626	0.282	0.089	0.367	1.000	0.235	0.538	0.591	0.328	0.505
81.370	0.503	0.807	0.757	0.499	0.235	1.000	0.571	0.623	0.518	0.561
98.544	0.768	0.768	0.384	0.701	0.538	0.571	1.000	0.890	0.616	0.742
120.197	0.900	0.769	0.351	0.630	0.591	0.623	0.890	1.000	0.647	0.879
435.889	0.751	0.628	0.257	0.495	0.328	0.518	0.616	0.647	1.000	0.625
696.708	0.878	0.711	0.292	0.639	0.505	0.561	0.742	0.879	0.625	1.000

Fig. 4. AutoMac matrix of eigenshapes.

It have to be mentioned that results of modal parameter measurement in which sensor S2 was used, are identical with those gained by sensor S1.

Measurement of operational vibration of transport complex during its movement was realized on railway road of length approximatelly 3600 m. The road was divided to 5 sections (see Tab.1) with considerably different characteristics of driving. In section No. 1 were recorded vibrations during starting of complex and during its movement through railway switches of railway station. Section No. 2 is characterized by driving through right bend. Section No. 3 is a straight road on the beginning of which is a railway bridge above road communication. Section No. 4 is left bended. In the section 5 that can be considered as straight road, the complex was stopped, accelerated and halting at the end of section. Maximum velocity of complex during measurement was 40 km/h, which corresponds to value received from operator.

Table 1. Lengths and short description of road sections**.**

Section number	Section length	Description of section
1	800 m	Movement from station – typically crossing several railway switches.
2	400 m	Right twist.
3	600 m	Relatively straight road.
4	150 m	Left twist.
5	1650 m	Relatively straight road.

For the measurement of vibration deflections were used three-component acceleration sensors Bruel&Kjaer 4506B, applied in locations S1 and S2. The sensors were connected to measurement system Bruel&Kjaer PULSE 3560 that records time-dependent charts of acceleration deflections to the hard disc of notebook. Measurement apparatus was supplied from portable electro-generator. From vibration analysis of transport complex acomplished during its moving results that maximum effective vibration velocity was 40 mm/s. This velocity was reached during acceleretion through railwai switches at the first section of road. Effective values of vibration accelerations determined from signals scanned by sensors S1 and S2 are for this section given in Table 2. Frequency spectra of maximum velocity amplitudes in directions *x*, *y,* and *z* in this section are shown in Fig. 5.

Table 2. Section No.1 – acceleration throught switches.

	X1	Y1	Z1	absolute value	X2	Y2	Z2	absolute value
v_{ef} [mm/s]	24,826	5,11	7,218	26,354	18,532	27,566	22,347	40,034

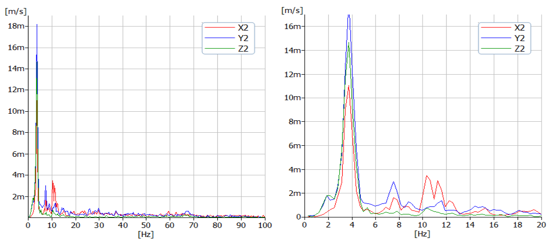


Fig. 5. Frequency spectrum of maximal vibration velocity amplitudes measured by sensor S2 on section No.1 during acceleration throught rail switch.

In order to determine excitation effect of locomotive motor to vibration of transport complex as well as for elimination of influence of voltage generator, measurement of frequency spectrum of maximum vibration velocities of unmoving transport complex with working motor of locomotive and voltage generator has been accomplished. From measurements result that the biggest amplitudes of velocities are in frequency range 2.5 to 2.8 Hz.

3. Drop and penetration tests with container model

The drop tests of packages can be accomplished, according to relevant regulations, on real containers or on models that properly represents their properties [1]. The tests were performed on 1:8 scale model according to Fig.6, made of steel 11523 and weight approximately 130 kg. Weight of real container without fuel bin is approximately 68 000 kg.

In accordance with Regulation of Nuclear Regulatory Authority of the Slovak Republic - ÚJD SR No.57/2006, the packages for transport of radioactive materials have to meet requirements declared for normal and accident conditions of transport. During the test, the container is falling onto a target (punch) - whereby the aim is to cause the maximum possible damage. Under normal transport conditions the height of falling, measured from the lowest point of specimen to the upper part of target, cannot be smaller than the distance given in Tab.3 for the given weight of consignment. According to the table, for test with a model with weight smaller than

5 000 kg height of the free fall should be 1.2 m. In case of drop test of real container falling on target the height of the fall should be 0.3 m.

Table 3. Hight of free fall for testing packages under normal transport conditions.

Weight of package [kg]	Free fall heigh [m]
Smaller than 5 000	1,2
5 000 or more, but less than 10 000	0,9
10 000 or more, but less than 15 000	0,6
more than 15 000	0,3

Impact effect caused by container drop can be modeled by falling from height 1 m on a steel punch of prescribed shape and dimensions and fixed perpendicular to the target (penetration test) [1]. Drop tests of packages were realized by free fall on test equipments. Drop tests of model were accomplished on test stand (Fig.7) that was designed and manufactured especially for this occasion and allows positioning of model.

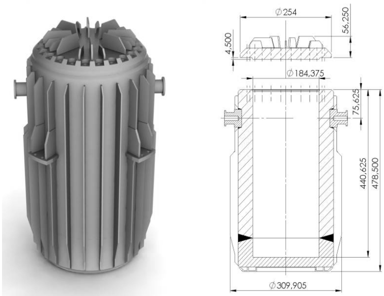


Fig. 6. Container model for drop tests.

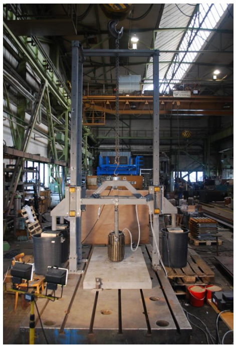


Fig. 7. Test stand for model drop tests.

The pad (target) for drop tests has to fulfill conditions defined by regulations [1,9,10,11]. The target for the drop test was the steel plate with mass approximately 1700 kg which was fixed to massive assembling plate. The drop tests should be realized in such position of container in which the most serious damage occurs. For the drop tests of model were chosen orientations according to Fig.8.

Before realization of drop tests analytical and numerical analysis of energy balance during the container falling was accomplished. The measurements confirmed that during the drop tests with drop height fall only h_0=600 mm plastic deformation occurs and accordingly it is not possible to extrapolate results to drop height 1200 mm, which is given by regulation [1], in case of using test object up to mass 5000 kg. In order to have data for extrapolation, the drop tests of container model were realized with fall height 0.30 and 0.60 m, respectively, and for orientation of model according to Fig.8.

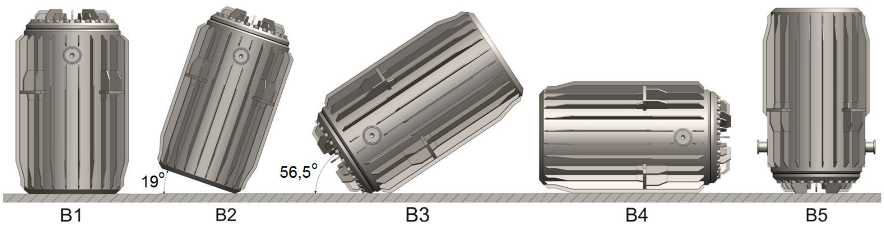
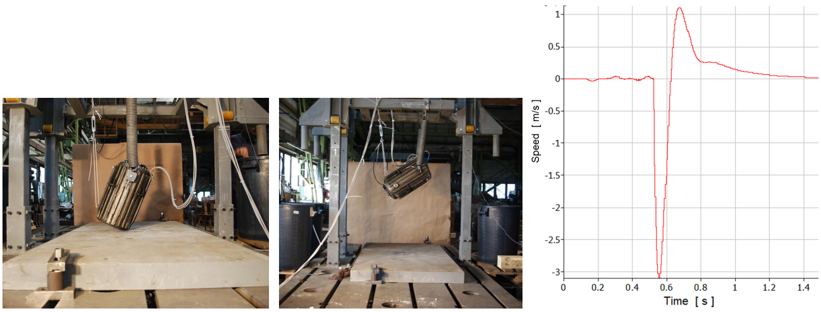


Fig. 8. Orientation of model for drop tests.

During the drop test were applied on the truck of test stand and on the lid of container model acceleration sensors. The strains were measured by strain gages applied on container model. Fig.9a, b. shows test stand during drop tests in model positions B2 and B3, respectively. For illustration purposes is for model position B2 and for fall height 0.60 m given in Fig.9c time-dependent chart of velocity determined on model by acceleration sensor.

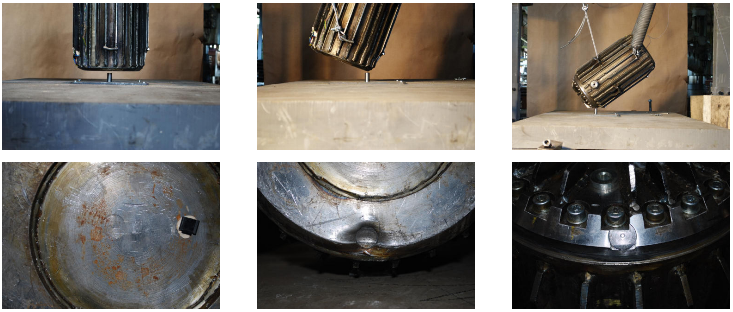


a) b) c)

Fig. 9. Test stand with a container model a) position of model B2, b) position of model B3 c) time-dependent chart of velocities, model position B2.

The penetration test of packages for radioactive material is prescribed by regulation [1] and it should demonstrate fact that package is able to withstand accidents during transport (failure conditions).

The opinion with small-scale models of containers shows that analytical assessments and numerical computations considering real values of material properties are comparable with results of experimental measurements [12]. Orientation of model with respect to the punch for individual penetration tests, i.e. positions of model at the moment of impact on a punch were the same as were during drop test but with labels C1 to C5. In order to take into account design of verified containers, the heights of falling do not differ very much from fall height 1 m for real container. The tests were accomplished on real stand for drop tests (Fig.7). For the penetration test were used acceleration sensors similarly as for drop tests (on the truck of test stand and on the body of container model). In Fig.10 are shown relative positions of model and punches as well as imprints of punch on the container model for penetration tests C1, C2, and C3.



C1 C2 C3

Fig. 10. Positions of model and spikes and trails on model after penetration tests C1, C2 and C3.

4. Discussion of results and conclusions

From the results of experimental measurements and vibration analysis of transport complex can be concluded that the biggest amplitudes of vibration velocity during movement were reached at the range frequency 3.8 - 5.0 Hz which correspond to eigenfrequency 4.342 Hz, Tab. 1. Maximum allowable velocity 100 km/h of transport complex can be, on the basis of modal and vibration analysis, considered to be suitable for transport. At the same time it is recommended to over cross the velocity 42-43 km/h as fast as possible, because the excitation of system at this velocity is near frequency 4.3 Hz. The other eigenfrequencies that result from analysis are not important for the technique of transport and accordingly no attention is given to them.

Experiments during drop tests were conducted on 1:8 scale model of container. Besides of rules of geometric model similarity were also fulfilled the principles of physical similarity for design of bumper on bottom of container model. Likewise, the rules of similarity were met during design of the container contents. Maximum velocities determined from measurements by acceleration sensors correspond to results of numerical computations very well and they allow assessing whole energy during impact, which is important for determination of accumulation degree or potential damage level. The measurements were conducted only for fall heights 0.3 and 0.6 m. The falls from greater heights were excluded in order to prevent possible damage of model that was used also for penetration and other model tests.

Stresses during impact are by their values, character and distribution along height of container model almoust the same with those gained from numerical analysis for model of the same shape and dimensions. If numerical computation of real container with the same methodology and under the same conditions is in the state where the integrity and tightness of container is preserved, then model tests can be considered as useful and the results confirm correctness of results of numerical analysis of container drop tests. Analysis of all drop tests concluded that the behaviour of container model agrees with results from numerical computations and similarly on the basis of computations can be stated that real container withstand all prescribed drop tests in the whole extent. Drop tests of container model on punch (penetration tests) were realized for all required positions of container model and the results allow to declare that the container model meet all requirements of regulations and accordingly the real container also withstand all required penetration tests.

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