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Experimental analysis as a part of type test of container for trasportation of spent nuclear fuel

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Abstract: For the verification of safety of packages determined for transport of spent nuclear fuel can be used stress analysis based on strain gages. In the frame of type tests of container was realized experimental analysis of residual stresses in the container body as well as stress analysis resulting from operation condinions, including mechanical and thermal influences. The results are compared with those gained by numerical simulation and they serve as a source of knowledge for assessment of life span of packages.

Keywords: container, residual stresses, mechanical and thermal influences

1. Introduction

For the certification of containers determined for transport of spent nuclear fuel is necessary to realize analyses that confirm fullfilling of demands of Regulation ÚJD SR No. 57/2006 [1]. For the verification process according to above-mentioned regulations can be used analytical, numerical, or experimental methods.

Computational verification of containers for transport of spent nuclear fuel was, in accordance with regulation [1], realized on the workplace of authors recently and it was approved fullfilling of all conditions [2]. At the same time, on the workplace of authors was elaborated methodology of experimental verification of package safety, by tests on real objects or models that represent essential properties [3,4].

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On the basis of suggested methods were, in the frame of type tests, realized extensive experimental analyses of stress states in the container body [5,6,7]. In the paper are given selected results gained during experimental analysis of residual streses in the container body as well as during stress analysis due to operation loadings that include mechanical and thermal influences.

2. Residual stresses in the body of container

For the measurement of residual stresses was applied strain gage method using drilling of hole [8]. With respect to conditions of drilling, it was necessary to choose strain gages RY 21, which have soldered output from their manufacturing. Equipment RS 200 was used for the drilling of holes. Methodology of hole drilling was in accordance with standard ASTM E 837-01 and TECHNOTE TN 503-6 [9,10].

In Fig.1 is shown analyzed container as well as position and orientation of strain gages for the hole drilling. Locations of measurement were selected on the basis of results of analytical and numerical methods [2]. They include areas of possible overloading during operation or radiation and thermal influences.

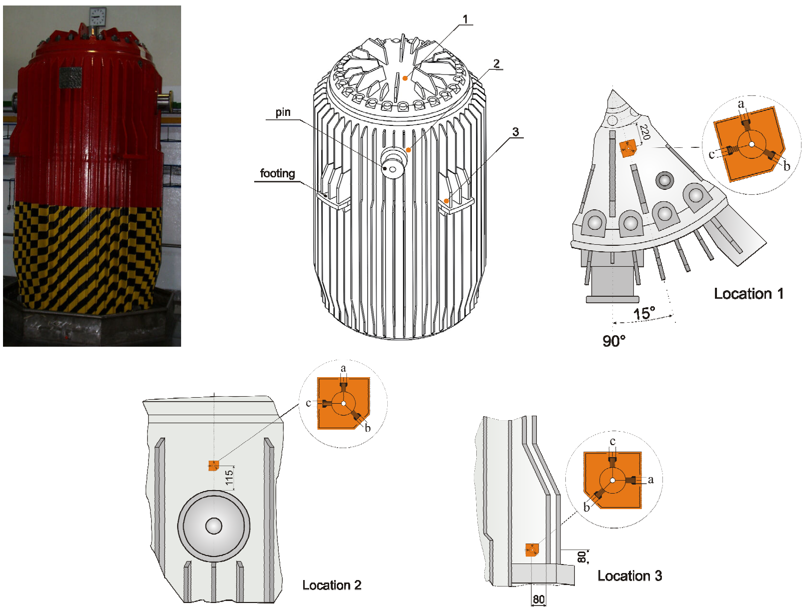


Fig. 1. Analyzed container, localization of strain gages for the hole-drilling method on the container body.

In Fig.2 are seen locations 1 and 2 in the process of hole drilling.

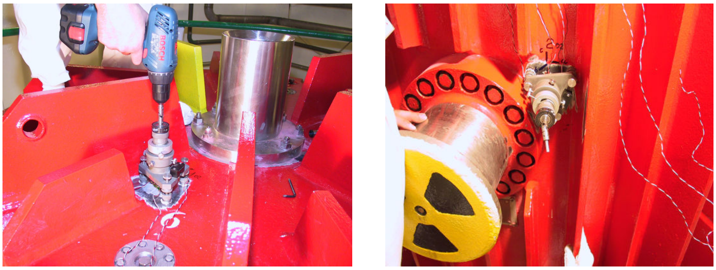


Fig. 2. Measurement locations 1 and 2 in the process of hole-drilling.

Application of strain gages was realized by strain gage joint cement X60 and isolation silicone protective coating SG-250. For the measurement was used strain gage apparatus P3. The diameter of holes was 3.2 mm, hole depth 5 mm reached by steps of length 0.5 mm (10 steps). Radius of strain gage rosette was 5.15 mm. In Tab.1 are given magnitudes of principal residual stresses and their directions in individual locations determined according to standard ASTM E 837-01.

Table 1. Magnitudes of residual stresses according to standard ASTM E 837-01

location of measurement	σ_{max} [MPa]	σ_{min} [MPa]	inclination angle σ_{max}
1	4,82	-13,70	47,46
	30,47	15,77	72,33
2	57,00	23,94	-77,86
	-3,75	-20,28	5,44
3	33,54	-26,83	6,15
	16,98	-9,13	-33,46

For the every location of measurement are given two values which belong to two different containers.

3. Experimental verification of container fixture

In accordance with supplement No. 1 of Regulation No. 57/2006, the lifting pins of container have to withstand all loadings resulting from manipulation with container by prescribed manners. It means that fixing equipment and whatever part of container used for lifting have to allow manipulation with container.

Analyzed type of container has four footings that serve for fixation of container to transport means, and two pins serving for manipulation with container (Fig.1). Because, according to the operator, the footings can not be used for lifting, there were experimentally checked only pins of container

The container pins were verified by classical manual computation as well as by using FEM and dynamic loading [2]. For the experimental verification of computed values of stresses (including verification of dynamic coefficient, which was assigned to be 1.4 in accordance with tables for lifting machines) the method of strain gage method based on electrical resistance was used. On top sides of container pins were applied strain gage rosettes XY 91, (for thermal compensation) in locations 9 and 10, near to the connection of pins to the container body (Fig.3).

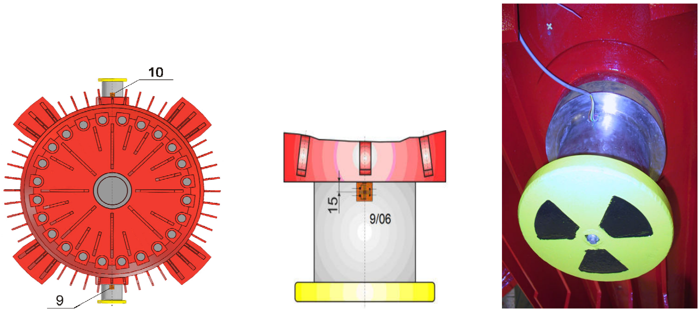
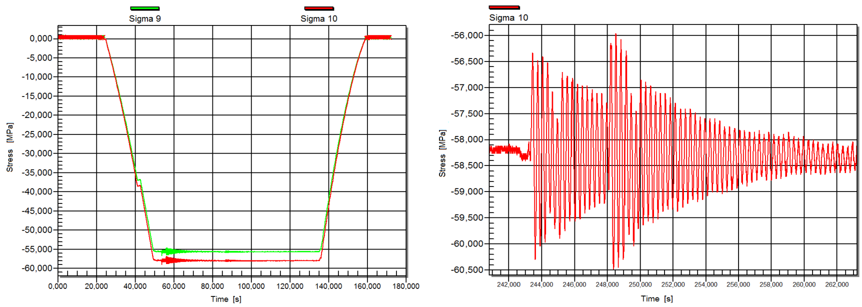


Fig. 3. Location of strain gages in positions 9 and 10 on the container pins.

Measurement was realized by strain gage apparatus SPIDER for various regimes of lowering and lifting by lifting equipment of operator.

In Fig.4a is given typical time-dependent chart of stress increments in the container pins during its lowering and lifting. In Fig.4b are shown time-dependent changes of stress increments reperesenting dynamic influence during starting of macroshifting of lifting.



a) b)

Fig. 4. Time-dependent charts of stress increments. a) during lifting and lowering of container, b) during macroshifting (lifting).

4. Thermal (and stress) analysis of container

The aim of thermal analysis of container was to show that after filling of container by spent nuclear fuel rods, the heat resulting from radioactive decay is not accumulated under prescribed transport and test conditions and the allowed limit temperatures and stresses are not exceeded in the body of container [1].

According to Regulation No.57/2006 Part VIII, outside temperature during using of transport container can lie in interval -40ºC to +38ºC. According to Section 14 Pert VIII, on easy accessible part of surface the temperature can not exceed 85ºC.

It is the reason, why for this relatively high temperature the safety parameters have to be determined and these have to be verified by experimental methods. The authors have chosen, with agreement of operator, the test by heating of operation medium in container. The procedure of test realization was based on instllation of heating coils in cassettes of container.

Electrical heating simulated residual heat due to radioactive decay in the internal container space filled by water. Control system of container heating ensured continuous regulation of maximum input 28.8 kW. At the same time it allows measurement of real whole heating power. 24 heating coils (everyone with power 1.2 kW) positioned in cassettes of container accomplished heating of whole container cross-section. Before measurement, installation of heating coils, sealing and filling of container by nitrogen to pressure 0.2 MPa had been accomplished.

In order to identify loading due to heating, on the container body were applied 8 strain gages, while four measurement locations (assigned 1 to 4) were on cooling ribs over fixation flanges and four assigned 5 to 8 (in pairs, because of plane stress state) were applied on the lid of container. Location of strain gages on the container body is given in Fig.5.

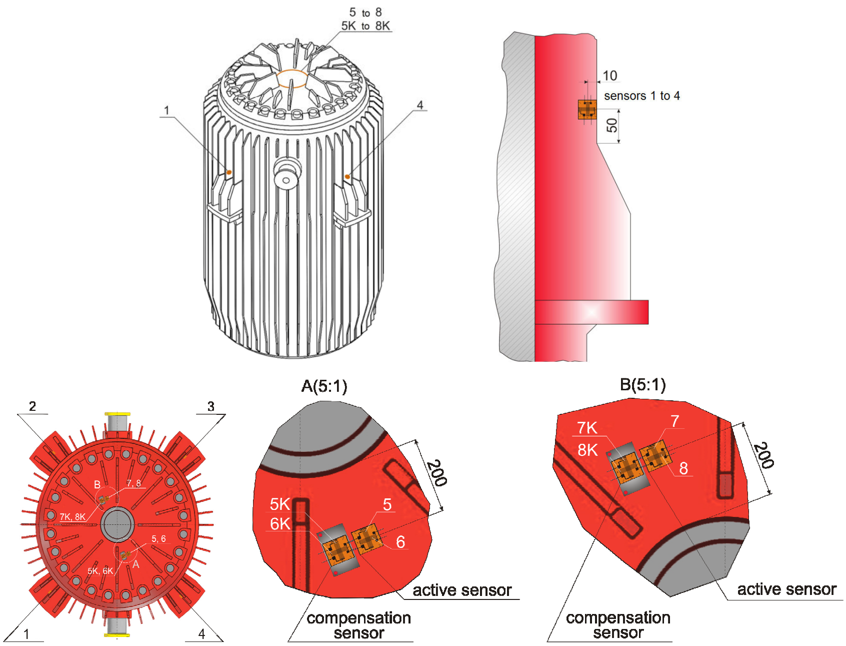


Fig. 5. Location of strain gages on the container body.

In order to ensure thermal compensation, in the locations of plane stress state, there were applied compensative strain gages 5K to 8K on unloaded steel sheets near to active strain gages. Numbers 5 to 8 mark the active strain gages (Fig.5).

The strain gage measurements were accomplished during three days in four positions on fixation flanges and four sensors on two locations on a lid, Fig.5.

At that time worked heating coils and there was measured temperature of water in the container cassette as well as temperatures of surface and environment. A thermovision camera also registered the temperatures of container surface. The charts of measured temperatures in individual time instants are given in Fig.6. Deliberate switching off air-conditioning in a room where the container was situated caused the change of environment temperature before end of measurement. In the location of sensor was reached maximum approximately 65ºC, while the temperature of water was tightly under 80ºC.

In graph in Fig.7 are given time-dependent charts of stresses during thermal test.

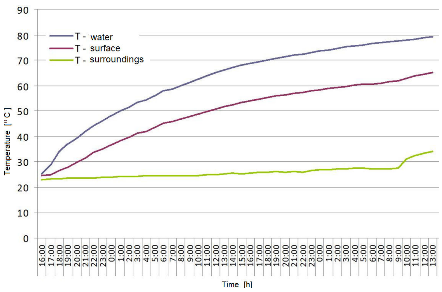


Fig. 6. Time-dependent charts of temperatures – water, surface, surroundings.

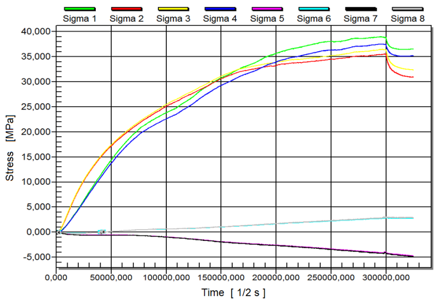
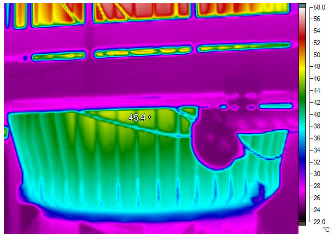


Fig. 7. Time-dependent charts of stresses during whole thermal test.

Broken curves in time-dependent charts of stresses (time approximately 150000 s) was caused by switching off airconditioning in the room, where the container was placed. At the time, when the airconditioner was turned off, the temperature of environment increased, while the increment of water temperature was constant (Fig.6) and surface temperature increased. This results to decreasing of strains in ribs (locations 1 to 4 in Fig.7).

The temperature of container surface was scanned by thermovision camera TiR1 during the whole thermal test. In Fig.8a is an example of photograph of container in the area of temperature measurement and in Fig.8b is given corresponding detail of container surface scanned by thermocamera.

a)



b)

Fig. 8. Measurement on the surface of container a) bottom part of container, b) detail of thermal stress on the surface of bottom part of container scanned by thermocamera.

5. Discussion of results and conclusions

On the basis of results of experimental measurements can be stated the following:

Results of measurement of residual stresses on the lid, body and rib document levels of residual stresses in individual elements of containers. As as mentioned above, the locations of strain gage application were chosen in order to register the highest levels of residual stresses during operation, manipulation and manufacturing. Selected locations allow using measurement system RS200. The highest levels of residual stresses were determined in location of container pin. The stress in that location is determined by the principal residual stresses σ_1 = 57 MPa , σ_2 = 24 MPa. However, these stress magnitudes do not represent danger for safe operation, because during vanishing loading that occurs here, there is no substantial decreasing of stress amplitudes in comparison to limit fatigue for symmetric cyclic loading.

From the stress measurement in the pins of container during its lifting and lowering results that the highest static stress level in pin reached in its absolute value 58 MPa, which is in agreement with results of numerical and analytical computations. Maximum stress amplitudes due to dynamic loading during manipulation with container had reached approximately 4.5 MPa. It defines experimentally determined value of lift coefficient 1.043, which is substantially smaler value than dynamic coefficient 1.4 considered during computations according to regulations for lifting devices.

Stress analysis of container under thermal loading due to heating by residual heat of radioactive decay of spent nuclear fuel had shown that for maximal temperature 65 °C in locations of applied strain gages, the stress increments did not exceed 40 MPa. With respect to the fact that the temperature on any easy accessible part of container surface cannot exceed 85 °C, it can be stated that the stresses due to internal heating with power of 24 kW do not influence lifetime of container body.

Thermal fields created by system of electric heating coils inside of container (scanned by thermovision camera) corresponds to thermal and stress fields gained by numerical computation by the finite element method under considering heating due to radioactive decay of spent nuclear fuel.

It can be stated that transport container, from the point of view of investigated situations, fulfils all requirements given by domestic and international standards for this type of equipments.

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