Experimental and Analytical Evaluation of Dynamic Loads on Shipping Cask Trunnions

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INTRODUCTION

The design of the lifting points (trunnions) of packages of radioactive material is part of the safety analysis in the transport licensing procedure. Transport regulations to be applied /1/ - in Germany identical with the IAEA-Regulations /2/ - demand a safe design in view of the different operating and transport conditions. These rather general safety requirements have to be quantified in connection with applicable regulations. For this purpose national and international standards are in preparation (/3/, /4/).

According to these standards a fatigue analysis is necessary, if a certain number of stress cycles is exceeded. The fatigue analysis requires a precise knowledge of the dynamic loads during handling and transport, because the lifting points are normally also used as attachment points for transport.

Because both NUKEM as a design engineer and BAM as the independent expert (working on behalf of the competent authority) were missing the required input data for a realistic fatigue analysis, experiments under handling conditions were performed jointly.

PURPOSE AND DESIGN OF TRUNNIONS

Trunnions are fitted to casks to provide:
- A means of tie down of the flask during transport on road, rail of sea and/or
- A means of providing lifting, of lifting and tilting.

Normally the trunnions are attached to the cask by welding, bolting or shrinkfit and bolting. In all experiments bolted trunnions were used. Fig. 1 shows a typical design of a trunnion. This trunnion has two shoulders, one for lifting and tilting and one for tie down during transport. The main stressed parts are the inner shoulder, the flange and the bolts. Stress concentrations occur were the diameters change.

REGULATIONS AND STANDARDS

The international standard ISO/TC85/SC5/WG9 /4/ concerns the standardisation of all aspects of trunnions used for spent fuel shipping casks. Included are design, fabrication and all matters relating to the "in service" life. National standards, for the German designers the KTA 3905, take precedence over this international standard. Both standards demand beyond a static analysis with certain loads, a fatigue analysis and provide a procedure to perform this work. But no data for load histories are included.

Fatique analysis is a function of cyclic stress intensity and stress cycles. During transport the cycle stresses and the number depend upon the mode of transport, the number of times the cask is transported and the transport mass. In case of lifting, the cyclic stresses and the number of stress cycles depend upon the crane, the number of crane operations and the lifting mass. According to KTA 3905 one has to assume 200 cycles for one lifting - movement - set down operation with repetitive stresses 1.8 times the static stress (Fig. 2), if you dont't have any information about the stress histories.

For one cask loading operation in a nuclear power plant we have about 10 lifting and set down operations. This means 2000 cycles for one loading operation, without the stress cycles during transport to the power plant. In addition the safety factor has to be 2.5 to the fatigue limit. For spent fuel storage casks with large weights up to 120 tons, this assumption seems to be too conservative. In the new draft of the KTA 3905 it is allowed to use more realistic stress histories gained from experiments or calculations.

PURPOSE OF THE TESTS

The purpose of the tests was to build a simple constant-amplitude sinusoidal stress cycle (stress range and number of occurrences) equivalent to the real stress history of a complete handling operation. The following data are of interest:

- influence of handled mass
- influence of the crane (stiffness compared with the handled mass)
- peak stresses and stress cycles by lifting
- peak stresses and stress cycles by movement
- stresses during set down
- pre-stress in the bolts and additional dynamic stresses under load
- stresses in the bolts compared with the stresses in the trunnions
- stress peaks in the trunnions where the diameters change

TEST PROCEDURE

One complete handling operation consists of lifting, movements with vertical accelerations and decelerations and set down. Thus every test was divided in three phases:
1) Lifting of the mass
2) Acceleration/Deceleration of the suspended load
3) Set down

During all operations the cask was accelerated as fast as possible to reach the maximal loads.

PRELIMINARY TESTS

A bolted trunnion under bending and shearing load is comparable with a ring flange system. Each bolt receives a different load. The additional stresses in the bolts under load depend mainly on the pre-stress in the bolts and the stiffness of the trunnion flange. To rate a trunnion with its attachment bolts the status of installation has to be well known. In particular, for bolts with large diameters this knowledge can be gained only by measurements due to the increase of friction. So the pre-stresses in the bolts during installation depending on the torque were measured by means of strain gauges. The influence of the torque on the pre-stress in a bolt M 42 is shown in Fig. 3. In a secondary static overload test the trunnions were loaded with 1.5 times the cask weight and the additional stresses in the bolts were measured. Only small additional stresses (less than 5 % of the yield strength) occured.

DYNAMIC HANDLING TESTS

The dynamic behaviour of trunnions under handling conditions was measured with two cask designs, one with 40 and one with 80 tons. To gain the influence of the crane also two types of bridge cranes were used. These cranes are comparable with cranes normally installed at nuclear power plants. The main crane data (Table 1) were:

max. load (tons)	bridge length (m)	lifting velocity (m/min)	total weight of crane (tons)
100	31	1 - 3	110
250	31	1 - 3	260

Table 1: Main data of the cranes used

To measure the strains in the trunnions and the trunnion-attachments (bolts) strain gauges were installed at the following locations:

- areas with maximum positive and negative bending stresses
- in the radius where the diameter changes
- bolts with maximum tensile stresses.

Test results

The measured modes of oscillations are schematically shown in Fig. 4. In the first moment of the lifting phase we have got the maximum amplitude $\hat{\sigma}$ of the vibrations. The oscillation is dying out relatively fast due to the system damping. Within about 10 periods nearly the static stress σ_m remains. During phase 2 we found similar modes of oscillation. The maximum amplitudes are about 50 % of the peaks in phase 1. Neglecticable vibrations occur in the phase of set down. Table 2 shows the measured peak stresses $\hat{\sigma}$ for the different test conditions and handling phases.

stressed part	mass of the cask (tons)	crane capacity (tons)	peak stress $\hat{\sigma}$ phase 1	peak stress $\hat{\sigma}$ phase 2
trunnion	40	100	1.08 σ_m	1.04 σ_m
trunnion	40	250	1.03 σ_m	1.01 σ_m
trunnion	80	250	1.05 σ_m	1.02 σ_m
bolt	40	100	1.10 σ_m	1.05 σ_m

Table 2: Peak stresses $\hat{\sigma}$ for different test conditions

For all test conditions only small peak stresses compared with the assumptions according to KTA 3905 were measured. In every case was $\hat{\sigma} \leq 1.1\,\sigma_m$. The amplitudes of the vibrations were less for the smaller mass. Because the automatically controlled shifting operations were softer, the heavy load crane (capacity 250 tons) produced smaller peak stresses than the crane with 100 tons capacity. In general one can say, that the influence of the crane and the handled mass was not very important. Nearly the same peak stresses were found in the bolts as in the trunnions.

The permanent recorded data enabled to determine significant parameters, necessary for the establishing of a suitable calculation method. A damping factor $D > 0.02$ was ascertained. Thus the assumption of a damping factor of $D = 0.01$ is sufficient for a conservative calculation. In a similar way a stress concentration factor of about 2 at the diameter changes was determined.

PROPOSED STRESS HISTORY FOR THE FATIQUE ANALYSIS

Based on these results we propose for heavy casks to use a stress history according to Fig. 5.

At the first moment of the lifting phase we assume a conservative peak load of 1.2 times the static load. This load is dying out within the next 10 periods to the maximum peak of the movement phase. For this phase we assume a constant-amplitude sinusoidal vibration with an amplitude of 1.05 times the static load. For one complete handling operation 10 accelerations or decelerations, each with 10 cycles, are realistic. Thus the number of stress cycles in phase 2 is about 100.

This load or stress history can be reduced to a simple constant amplitude sinusoidal-stress history with an amplitude of $1.2\,\sigma_m$ and an equivalent number of stress cycles of about 5.

DYNAMIC LOADS DURING TRANSPORTS

It is intented to continue the experiments with respect to the investigation of the actual shipments. There is also reliable data still missing in this field.

First measurements with a 100 t cask transported by train show, that the maximum loads (coupling in railway stations, railroad crossings, etc.) are comparable to the peak loads of handling. Additional measurements have to be performed.

REFERENCES

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GGVS, 22. Juli 1985

/2/ Regulations for the Safe Transport of Radioactive Materials, 1985 Edition, International Atomic Energy Agency (IAEA), Vienna 1985

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KTA Dokument Nr. 3905/86/1; Regelentwurf Mai 1988

/4/ ISO/TC85/SC5/WG9 - Trunnions for Spent Fuel Shipping Casks
Sixth Draft, May 1988

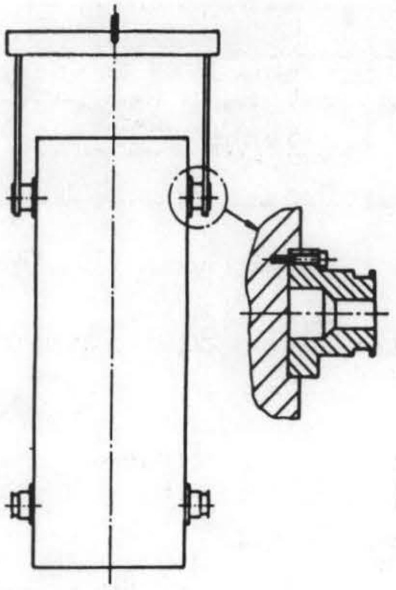

Figure 1: Design of a bolted trunnion

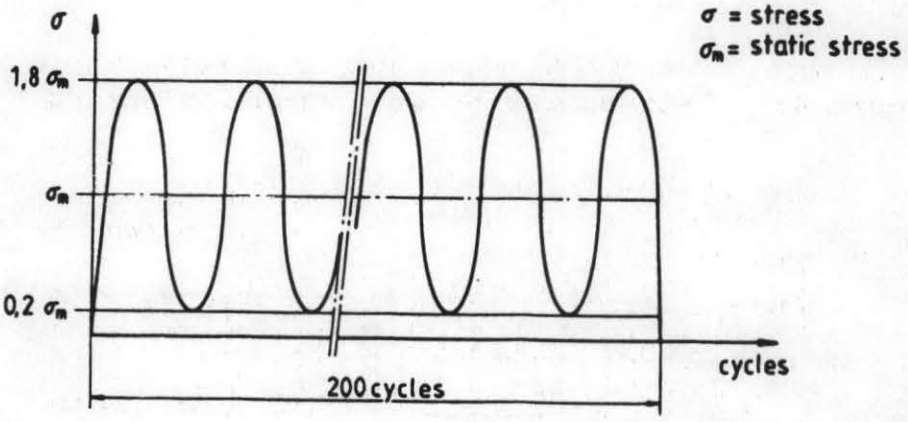

Figure 2: Stress history for one handling operation according to KTA 3905

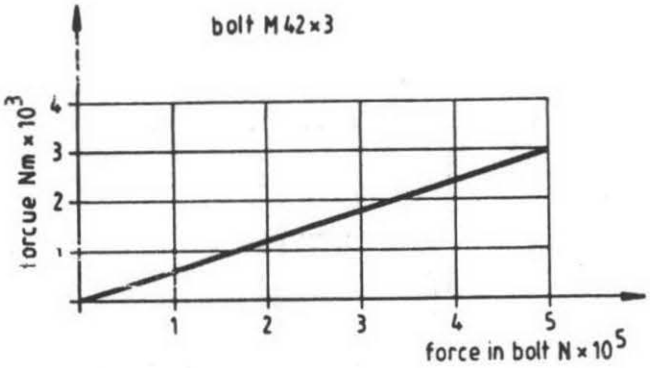

Figure 3: Influence of torque on force in a bolt M 42 x 3

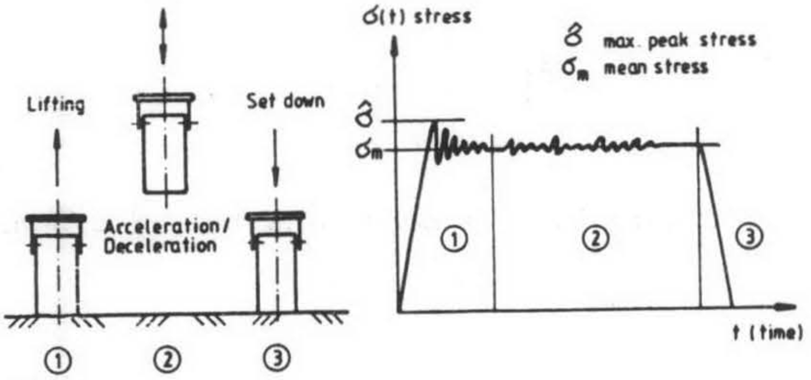

Figure 4: Stress cycles at a trunnion during handling

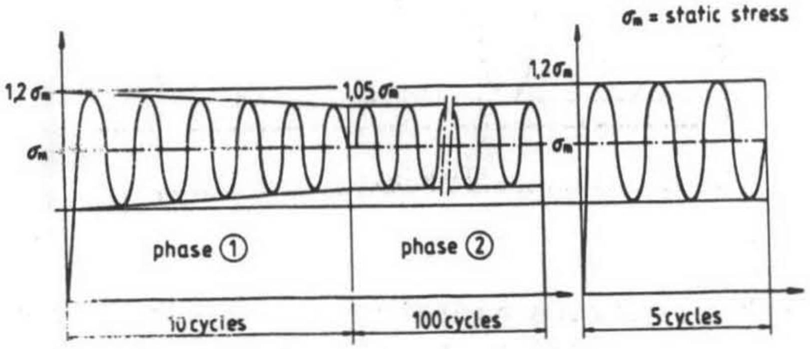

Figure 5: Proposed stress history for a complete handling operation