Standards and Guidelines for the Design of Trunnions of RAM Transport Packages-17365

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Abstract

Trunnion systems of packages for the transport of radioactive materials have to guarantee the safe handling of package during crane operations (lifting, tilting) and to secure package tie down to the transport vehicle, if the trunnions are used as attachment points during transport. The design of trunnions is based on IAEA Regulations SSR-6 [1], the supporting Advisory Material SSG-26 [2] and further appropriate technical standards and/or guidelines. For package approval procedures in Germany the guideline BAM-GGR 012 [3] has to be applied. If a package is handled inside a german nuclear power plant, the standard KTA 3905 [4] has to be fulfilled additionally.

In this paper the requirements of KTA 3905 [4] concerning the trunnion systems as load attaching points (LAP) are discussed in connection with the recommendations in the guideline BAM-GGR 012 [3]. This guideline is prepared at BAM Federal Institute for Materials Research and Testing for analysis and assessment of bolted lid and trunnion systems of Type B(U) transport packages. The quality assurance questions concerning trunnion systems are discussed as well.

Introduction

Trunnion systems as parts of Type B packages for radioactive materials (RAM) shall be designed in accordance with the IAEA SSR-6 [1] with the aim of ensuring safe handling (to lift, to drop and to rotate) and safe transport under Routine Conditions of Transport (RCT) when the trunnions are engaged during transport.

The load assumptions and the evaluation criteria for the stress analysis of trunnion systems are described only generally in the IAEA regulations [1]. Similarly the quality assurance measures are not sufficiently defined in these regulations. The KTA 3905 [4] is used in Germany for handling in nuclear power plants. This safety standard applies to any type of LAPs, e.g. also to trunnions for RAM, and is one of the references in IAEA SSG-26 [2] on the topic of load cases for designing trunnions. Another international standard for the design of trunnions is ISO 10276 [5]. It doesn't replace the national standards but it supplements the IAEA's recommendations. The scope of application of ISO 10276 [5] includes bolted, welded and press fit connected trunnions. Maximum accelerations under RCT are defined e.g. in the Advisory Material SSG-26 [2] or in ISO 10276 [5]. The load factors for lifting are also mentioned in ISO 10276 but the KTA 3905 is to be used for the handling of RAM packages within german nuclear power plants. The design loadings according to DIN 15018-1 [6] can be used for handling on public roads and outside of German nuclear power plants. The requirements for materials, production and in-service inspection are mentioned in KTA 3905 [4], BAM-GGR 011 [7] and ISO 10276 [5].

The stress assessments in KTA 3905 [4] and ISO 10276 [5] are based on the evaluation of nominal stress. Since the geometry of the trunnions frequently leads to the fact that the application of the nominal stress concept is not possible, the stresses are increasingly calculated with a three-dimensional finite element (FE) model. For this reason, it is necessary to have a concept for assessment of local stresses. BAM-GGR 012 [3] includes such an evaluation concept and summarizes moreover the essential aspects for designing of bolted lids and trunnion systems.

With regard to the mentioned guidelines, this paper primarily describes the mechanical design and the quality assurance measures using the example of bolted trunnions. The different loads assumptions and the various assessment criteria for stress analysis are discussed exemplarily.

Geometry, structure, function and loads

Usually, RAM packages have four trunnions, each of it is fastened to the cask body in pairs by means of bolted joints in the cask top and bottom area (Fig. 1). The design of trunnions is carried out for masses in the range of approximately 1,000 kg to 150,000 kg. The trunnions consist predominantly of stainless steel. For designing, the load cases of the trunnions during handling and if relevant during transport on public routes are taken into account.

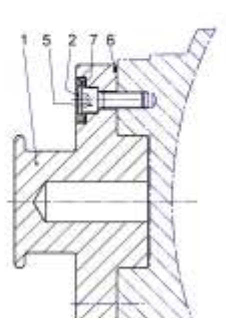

Fig. 1: example of trunnion construction

In the case of loads resulting from handling, a distinction is made between crane handling within and outside nuclear power plants. Furthermore a temperature range from -40 °C to 85 °C or, if higher, up to the maximum operating package temperature [1] has to be considered.

Because the design has to comply with both the IAEA regulations [1] and the handling within the scope of the KTA 3905 [4], the requirements of the two legal areas must be considered together. Thus, three different load states are distinguished, assembling, handling and transport.

Assembling state

The preload or pretension of the bolts is relevant for the assembling state of the LAP. An established guideline for the bolt calculation is the VDI 2230 [8]. Both the KTA 3905 [4] and the BAM-GGR 012 [3] apply this guideline. Important for describing the stress of the trunnion bolts is the possible range of the preload due to imprecisions in the tightening method and a dispersion of friction conditions in the threads and under the bolt heads. For that a suitable tightening factor according to the tightening tool has to be found together with a covering range of friction coefficients for the materials used. In the case that these values are not available by standards or manufacturers information, experimental investigations can be necessary.

On the base of this analysis the minimum and the maximum bolt preloads are calculated for the tightening torque specified. In addition, the setting effects in the bolted joints as well as possible reductions due to temperature changes are to be included in the definition of the minimum pretension.

Load assumptions for general (static) stress analysis

A description of load cases covering the various transport and handling situations of the package must be provided in preparation to static stress analysis. Operational situations like underwater package loading should be recorded as well. Other handling loads for example a change of the transport cask weight (handling without shock absorbers, tipping safety devices which have attached the cask) has to be considered.

The usual load case is given by a product consisting of a load factor multiplied with gravity and the corresponding mass. Within the area of application of the KTA 3905 [4], special load factors are applied, which on the one hand include additional safety factors and on the other hand take into account the higher requirements for crane systems. For handling on public transport routes, a lifting load factor for cranes of lifting class H4 according to DIN 15018 [6] is applied in BAM-GGR 012 [3]. The load factors for the static stress analysis are shown in Table I.

Scope of application	**Load factor**
Increased requirements acc. to KTA 3905	1.8
Additional requirements acc. to KTA 3905	1.35
General requirements for crane operations	1.45
Transport on public routes	2.0

Table I Load factors [3]

If trunnions are used not only for crane handling, but also used as part of the tie down system during transport an appropriate load factor must be defined too. This load factor depends on the modes of transport (road, rail, sea or air). The load factor for a transport on public routes given in Table 1 as an example corresponds to longitudinal and transverse directions of road transport according to IAEA SSG-26 Appendix IV, Table IV.1 [2]. Further data of load factors are e.g. in ISO 10276 [5]. In addition, it is possible under RCT to use lower load coefficients than those specified in BAM-GGR 012 [3], IAEA SSG-26[1] [2] or ISO 10276 [5] if these values are adequately justified.

Load assumptions for fatigue strength analysis

For crane handling and for transport on public routes, an additional fatigue analysis is required in addition to the static stress analysis. According to KTA 3905 [4] a fatigue evaluation should be carried out after more than 200 (for converter drives and cable drives with creep speed) and 100 (for other drives) operational load cycles. An operational load cycle is the process between taking up and setting down of the load. The number of stress cycles within an operational load cycle is set according to KTA 3905 [4] for drives with creep speed with 30 and for other drives with 60.

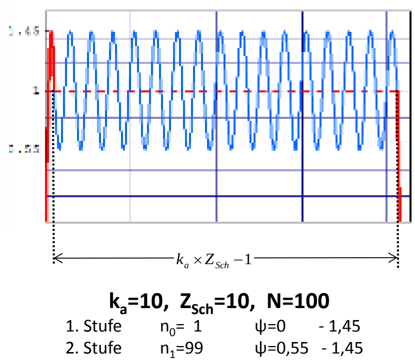

Fig. 2 two-step load collective

If a fatigue analysis is required, a damage-equivalent single-step load collective can be created according to KTA 3905 [4] under consideration of the number of operational load cycles with the associated number of stress cycles. In this case the maximum stress corresponds to the maximum value of the load amplitude after the coupling of the cask and is calculated taking into account the load factors specified in KTA 3905 [4] for the respective requirements. The minimum stress is equal to zero for the trunnions and to pretension stress for the bolts.

In contrast to KTA 3905 [4] the application of a two-step load collective (Fig. 2) is recommended in BAM-GGR 012 [3]. This allows uniform treatment of the crane's handling independently from the handling area as well as the combination with transport load collective if necessary. The first step (once per load cycle) is for taking up and setting down of the load. The remaining cycle consider stress caused by the oscillation during the load movement between taking up and setting down. For drives with creep speed 99 stress cycles must be considered at this step. For other drives this number increases to 199. Table 2 shows the load factors to be used for the

[1] The Advisory Material SSG-26 is under revision and will get new data as regards the acceleration factors for package retention systems design. See [20] for more information.

determination of the stress collective with which the loads to be taken into account are to be multiplied.

Collective step *Number of stress cycles*	I 1	II 99 resp. 199
Scope of application	*Load coefficient*	
Increased requirements acc. to KTA 3905	0 . . . 1. 45	0.55 . . . 1.45
Additional requirements acc. to KTA 3905	0 . . . 1.35	0.65 . . . 1.35
General requirements for crane operations	0 . . . 1.45	0.55 . . . 1.45

Table II Load factors for load cycles during crane handling [3]

As it is not possible to define universally valid stress collective for a transport on public routes these should be defined both on the basis of the requested modes of transport (road, rail, sea or air) and the length and number of transports. In order to comply with these possible or planned transports, appropriate fixings must be included in the instructions package manual. If transports are carried out under conditions which are not covered by the safety analysis, new or additional analysis for cyclic operation has to be done. In addition to experimental verification published measurements can also be used for transport collectives [9,10,11,12]. However, the application on other constructions or transport distances, as well as the consideration of measurement errors, may necessitate the use of additional safety factors in the analysis for cycling loading.

Numerical stress analysis

Conventional analytical methods referring to the strength analysis of the trunnion systems are based on the beam theory. The compact trunnion structure (relation of height to diameter) combined with evaluation points near the load exceed the formally applicability of these methods.

Advanced methods, e.g. FE analysis, lead to more accurate results and allow furthermore a direct simulation of interactions between components of the trunnion system in the same calculation step [13]. For this reason the FE model should content the trunnion, fastening bolts, and an appropriate part of the cask around the recess for the trunnion’s spigot. Based on such models the stress and strain distributions in the trunnion itself and in the bolts can be calculated for all loading conditions to be considered.

The interpretation and preparation of the calculation results for final conclusion about the design compliance with the requirements depend upon the assessment concept (nominal or local one) for the particular component of trunnion system. In general a linearization of stress fields calculated by FE analysis and determination of a nominal stress, as e.g. proposed in [5], is not applicable for trunnions having no well-defined cross section. Therefore the assessment criteria for the trunnion itself is defined in [3] for local values of stress. On the other hand it is reasonably to retain the nominal stress concept for strength assessment of the bolts owing to their simple rod shape. BAM guideline [3] recommends transforming the local stresses in the bolts from FE analysis into nominal ones, hence the following analysis (e.g. fatigue evaluation) is able to be performed according to the guideline VDI 2230 [8].

In BAM guideline [3] the assessment criteria for general stress and fatigue strength analysis are defined. As an example the criteria for general analysis will be summarized in this paper.

The following criterion shall be fulfilled for the maximum local equivalent (von Mises) stress in trunnion σ_v

$$\sigma_v \leq \frac{R_{p0.2}(T)}{1{,}5}$$

where $R_{p0.2}(T)$ is a 0.2% proof stress of trunnion material under operation temperature. If this condition cannot be satisfied, a limit load analysis must be carried out additionally to demonstrate the structure reserves against a plastic collapse. In this elastic-perfectly-plastic analysis with $R_{p0.2}(T)$ for the yield point, the design loads (Table 1) have to be multiplied by factor 2.25. If convergence in the numerical analysis is achieved, the trunnion system is stable for the load case under consideration.

The use of solid finite elements for the modelling of trunnion bolts is generally recommended according to BAM guideline [3]. VDI 2230 [8] can be used to calculate the tensile stress (pretension) $\sigma_{z,Mon}$ and torsional stress $\tau_{G,Mon}$ in the assembling state of the trunnion bolts. The equivalent stress is formed then by equation

$$\sigma_v = \sqrt{\sigma_{z,Mon}{}^2 + 3\tau_{G,Mon}{}^2}$$

The assembling state is simulated in the FE model by preloading the bolts with the initial tensile stress $\sigma_{z,Mon}$. In the next calculation steps the operational loads are applied to the model. The transformation of the local stresses into nominal ones is necessary for strength assessment of the bolts under these loads. Axial forces and bending moments are derived from the nodal forces of FE-model for each section along the clamping length of the most heavily stressed bolt. The evaluation of the average tensile stresses and the maximum total stresses including bending and torsion is shown in the following equations

$$N = |\boldsymbol{N}| = \sum_i \ F_{1,i}$$

$$M_b = |\boldsymbol{M}_b| = \sqrt{M_2^2 + M_3^2} \qquad M_2 = \sum_i \ r_{3,i} F_{1,i} \qquad M_3 = -\sum_i \ r_{2,i} F_{1,i}$$

$$\sigma_z = \frac{N}{A} \qquad \sigma_b = \frac{M_b}{W}$$

$$\sigma_v = \sqrt{(\sigma_z + \sigma_b)^2 + 3(k_T \tau_{G,Mon})^2}$$

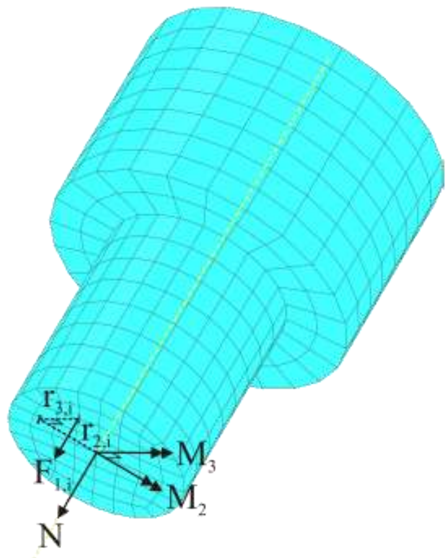

Fig. 3 force and moments

The criteria (nominal stress) for the general strength assessment of the bolts in the assembly state and the operational conditions are summarized in the following Table III.

Scope of application	Allowable stress			
	Assembly		Operation	
Increased requirements acc. to KTA 3905	$\sigma_v \leq$	0.7 $R_{p0.2}$ (T)	$\sigma_v \leq$	$R_{p0.2}$ (T)
Additional requirements acc. to KTA 3905	$\sigma_v \leq$	0.7 $R_{p0.2}$ (T)	$\sigma_v \leq$	$R_{p0.2}$ (T)
General requirements for crane operations	$\sigma_v \leq$	0.9 $R_{p0.2}$ (T)	$\sigma_v \leq$	$R_{p0.2}$ (T)
Transport on public routes	$\sigma_v \leq$	0.9 $R_{p0.2}$ (T)	$\sigma_v \leq$	$R_{p0.2}$ (T)

Table III Criteria for the general strength assessment of the bolts [3]

In the area of KTA 3905 application an additional condition have to be fulfilled for the tensile stress in the trunnion bolts under crane operations:

$$\sigma_z - \sigma_{zMon} \leq 0{,}1R\mathrm{p}0{,}2(T)$$

If a limit load analysis is required for the trunnion system, the bolts are modelled with an elastic-perfectly-plastic material law in order to ensure a realistic load distribution. $R_{p0.2}(T)$ value of bolt material has to be used as the yield point. The limit load analysis is only needed for additional verification of the trunnion design. The strength assessment of the bolts is not necessary under such overloading.

Quality Assurance Measure

Packages for RAM and their trunnions are subject to national and international regulations. The German national regulations are the GGVSEB [14], GGVSee [15] and the LuftVZO [16]. They comprise all modes of transport and are based on recommendations for the safe transport of radioactive materials IAEA SSR-6 [1]. The necessary measures for quality assurance during design, construction, manufacture and operation are explained by two guidelines: for packaging which is subject to regulatory requirements in BAM-GGR 011 [7] and for packaging which is not in BAM GGR 016 [17]. In KTA 3905 [4], there are also requirements for quality assurance measures in the case of handling casks within nuclear power plants.

The measures for quality assurance are divided into company-specific processes and packaging-specific processes. Company-specific processes are regulated in the quality management system and are described in the form of a quality management manual (QMM) based on the ISO 9001 series [18]. The following points are described in QMM:

- organization of operational procedures
- responsibilities
- technological requirements
- organizational structure, qualification, internal audits
- cooperation of development, production, quality control and operation
- cooperation with experts and authorities

The system-related measures are checked by BAM in 3-year intervals, e.g. by audits.
The packaging-specific measures are regulated in the quality management plan and can be divided into the following items:

- monitoring of production
- design and permissible content
- acquisition materials, measures for deviations, manufacture of packaging
- instructions for operation, maintenance and in-service inspection

The applicant or approval holder must ensure that the packaging-specific measures are implemented.

Materials

In KTA 3905 [4] and ISO 10276 [5], detailed requirements for materials, tests for before and during manufacture and specifications for in-service inspection are described. For example, in KTA 3905 [4], material test sheets for various materials and their product form are listed in Annex A [4]. The material test sheets contain the material tests to be carried out and the applicable standards, as well as the test participation according to DIN EN 10204 [19]. In ISO 10276 [5], mechanical properties, such as permissible notch bar impact value and the minimum elongation at break, are given.

Generally

The manufacturer of trunnions for transport cask for radioactive materials shall have a quality management system appropriate to the manufacturing scope as well as sufficient human resources and adequate infrastructure to ensure product quality [7]. The manufacturer's qualifications are to be verified by the BAM or qualified experts before the start of production and is reviewed every three years.

Transport Package Design approval

The transport package design approval consists of checking and approving the documentation necessary to ensure the packaging-specific specifications in the production of trunnions. BAM-GGR 011 [7] describes the concrete production and inspection plans, including the associated work and inspection instructions, part lists, drawings, welding plans, material test sheets and where applicable further documentation for production and commissioning can be found. The design approval shall be carried out by BAM or other experts before the start of production. In the field of KTA 3905 [4], an additional strength calculation is assessed during the design approval irrespective of whether or not an approval according to IAEA SSR-6 [1] is available.

Final inspection

A detailed description of the tests to be performed during manufacture is defined in Table 8-1 in KTA 3905 [4]. There are tests such as material identification, testing of bolts and screw threads, the welding torques, nondestructive testing, the tightening torque of the bolts, and the test monitoring by external experts. ISO 10276 [5] also defines guidelines for tests to be carried out during production.

An acceptance test should be carried out before start of operation. For this purpose, the KTA 3905 [5] also provides an overview of tests to be carried out, such as carrying out a load test with load factors of 1.25 with dynamic load application or a factor of 1.5 with static load application. For welded trunnions, non-destructive surface tests must be carried out after the load test. With bolted-on trunnions, permanent deformation should be excluded.

In-service inspection

Transport casks and their trunnions are to be periodically monitored. The aim for that is the confirmation that the properties specified in the cask approval are complied with at the time of the test and are observed until the next in-service inspection. In KTA 3905 [4], a distinction is made between 1 year, 3 years and 6 years of in-service inspection. Tests such as tightening torques of the bolts, checking of the screw thread by means of a thread plug gauge are carried out every 3 years. Loading tests are carried out every 6 years. The results of the tests shall be summarized in a certificate and shall be issued by BAM or a commissioned external expert.

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