BAM

Federal Agency for Material Research and Testing

Expert Group III.3 “Safety of Transport and Storage Casks”

BAM – GGR 009

Guideline for Calculating Lid Systems and Load Attachment Systems for Radioactive Material Transport Casks

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1 Introduction

1.1 Utilization and contents of the guideline

This guideline concerns the design of the lids and load attachment systems of radioactive material transport casks. It provides indications concerning load assumptions, the utilization of calculation methods and evaluation criteria for the approval of the above mentioned cask. The guideline primarily relates to the casks defined as to their characteristics in [17] for Type B packages. It may, however, also apply to other casks used to transport radioactive materials. It must be taken into account when working out safety verification reports for radioactive material transport casks.

In this guideline, the isolated consideration of single structural parts is extended by a system consideration, in order to also grasp interactions between structural parts. In doing this, the closing system with several lids or lid systems and the load attachment system are taken into account, based on the package. This consideration is complemented through the examination of single components of these systems. This modeling hierarchy allows taking into account of several multiple interactions between the partial systems of the package, between partial systems and the corresponding structural parts and between the single structural parts.

Next to the actual lids (primary lid, secondary lid, small lids etc.), the closing system comprises the corresponding screw and sealing systems. For example, a load attachment system consists of a load attachment point (trunnion, grapple etc.) and the corresponding fastening screws.

The base for the consideration of the lid system are the requirements for routine, normal and accidental transport conditions of radioactive material packages based on the legislation concerning dangerous goods. Furthermore, the criteria which must be taken into account are also discussed related to the assembling of the screwed fastenings. Concerning the load attachment systems, next to the verification for the assembling conditions of the screwed fastenings, the requirements towards the static and operating solidity of system components are treated as a supplement in this guideline. The requirements take into account the stresses on the load attachment systems, both when being handled with a crane (transport with a crane) and during transport over public paths.

This guideline is limited to the questions of general stress verifications and of verification of resistance to fatigue of components assumed to be faultless. If necessary, supplementary verifications will be required for mechanical fracturing considerations, based for example on the *Guideline for the Utilization of Cast Iron with Nodular Graphite for Transport and Storage Casks for Radioactive Materials* (GGR 007) [5].

The safety factors indicated in this guideline assume realistic, or when this is not possible, conservative modeling, especially concerning geometrical idealization, the spread of the characteristic values of the used structural materials and the load assumptions. This modeling should be justified and checked for the corresponding calculations.

This guideline was prepared by Expert Group III.3 “Safety of Transport and Storage Casks” of the Federal Agency for Materials Research and Testing, within the scope of project “0207-III.32-0090: Safety Technological Expertise and Approval of Transport Casks for Radioactive Materials”, in order to bring together the essential aspects for the verification of the lid and load attachment systems of radioactive material transport casks. The designers of a cask must check and, if necessary, justify whether the conditions set forward in this guideline must apply after being completed or changed. Stress scenarios which are not considered in this guideline must be considered separately.

1.2 Legal Base

National and international traffic regulations for the transport of radioactive materials are all based on the recommendations of the International Atomic Energy Organization (IAEA) [17]. The mentioned recommendations have been taken over bindingly through the regulations for dangerous goods in both national and international legislation for the different carriers, e.g. road, rail, water, air, e.g. in ADR or in the Maritime Dangerous Goods Ordinance [1] [15].

When designing transport casks for radioactive materials, legal traffic regulations are mainly aimed towards the fulfillment of the following functions:

- Tight containment of the radioactive contents (both integrity and tightness),
- Shielding off of the radiation emitted by the contents,
- Assurance of sub-criticality of the contents (in the case of fissile materials).

Next to the shielding and sub-criticality, the lid systems of the transport cask must also assure the safe enclosure of the contents, together with specified requirements towards the tightness of the cask. Load attachment systems shall assure the safe handling of the casks and their components, as well as their safe fastening on board the transport carrier vehicles.

Mechanical and thermal stresses appear as a result of the above mentioned tests for routine, normal and accidental transport conditions, which must be taken into account as load assumptions in the safety verification reports. When doing this, stresses acting on the cask during normal operation must be taken into account as routine transport conditions. Slight transport accidents are accounted for under normal transport conditions, corresponding to a drop from 0.3 to 1,2 m, depending on the mass of the package (§ 722 in [17]). On the other hand, accidental transport conditions comprise severe traffic accidents, simulated for example by means of cumulated tests including a drop from 9 m height on an unyielding base, followed ba a drop from 1 m onto a steel bar and by a fire of an average temperature of 800 °C lasting for half an hour. Furthermore, a water seep in test through immersion at 15 m depth (200 m depth for packages loaded with fissile material) must be performed [1] [17].

Regulations concerning dangerous goods legislation consider tests with prototypes or series specimens as verification methods, with reference to previous tests performed on casks of similar structure, furthermore tests with scale models, calculations or justified assumptions, as well as combinations of several of these possibilities, as valid proofs [1] [17]. This guideline refers to specific methods of calculation based proof, based on a conservative or experimental verification of the basic parameters and assumptions.

1.3 Other standards and directives

Specific directives exist for different structural parts used for radioactive material transport casks, to which reference is made in this guideline. Thus for example, when designing screwed connections, VDI Directive 2230 [28] corresponds to the state of the art; when designing load attachment systems, this is the case for KTA Directive 3905 [22] concerning vehicle transports within nuclear facilities, as well as ISO/TC85/SC5/WG9 [20] for public transports.

However, requirements towards transport casks for radioactive materials resulting from legal traffic regulations partially go farther than the cases treated in the above mentioned documents. Thus, for example, VDI Directive 2230 [28] only permits insufficient modeling and calculation [23] of gaps resulting from special lid system gasket arrays. The multi stage considerations according to legal traffic regulations involving routine, normal and accidental transport conditions especially require differentiated evaluation criteria which are not covered in this form by existing directives and standards.

Furthermore, except for exceptional cases, y systematic consideration of the lid area and of the load attachment points is required in order to be able to take into account interactions with other package structural parts (e.g. between lid and shock absorbers). As a rule, a numerical analysis is necessary for this kind of consideration, allowing for a realistic calculation of the lid and load attachment systems.

For numerical analyses, the *Directive for Numerical Safety Verifications within the Scope of the Design Approval of Transport and Storage Casks for Radioactive Materials (GGR 008)* [6] must be taken into account in order to assure the application of numerical calculating programs yielding sure results. The assessment of these numerical analyses and the evaluation of the results related to existing regulations and rules are part of this guideline.

2 Lid systems

Conventional radioactive material transport casks are designed with a lid including leadthroughs, the lid being fitted with elastomere gaskets. The closing system of transport casks according to the variant used for long term interim storage conceived in Germany [7] (double barrier) usually consists of a primary lid, a secondary lid, small lids, screws with the corresponding tapped holes, and gaskets. Each of the diverse lids with their corresponding components (screws, tapped holes and gaskets) constitute a lid system.

The main function of the closing system is to assure tightening functions. Thus, as a rule, all its components are part of the tight containment of the package. In the case of a double lid system, the sealing function is assured by the primary lid system and, according to the concept, alternatively or complementarily, also by the secondary lid system. Furthermore, the primary lid especially assures a supplementary shielding function. The small lids integrated in the primary lid assure access to the interior cask cavity during its handling after being loaded. The secondary lid and the small lids integrated in it are, as a rule, parts of the system assuring the supervision of tightness during long term storage of the cask in an interim storage facility.

2.1 Calculating methods and modeling

In order to allow for a demonstration and verification of the complete closing system under routine, normal and accidental transport conditions under conditions as realistic as possible, as a rule, a numerical solidity analysis must necessarily be carried out, even after empirical tests, using preferably the finite element method. The interactions between the single structural components of the closing system can only be exactly described by means of a complex calculating model and calculating methods. FE analyses for shock type stresses affecting the closing system under normal and accidental transport conditions may be carried out quasi statically if it is possible to demonstrate that dynamical effects only have a negligible influence on the stress affecting the structural components.

Should it however be necessary to use analytical calculation methods in exceptional cases, it must be ascertained that the aforesaid interactions are adequately taken into account, and especially that the superimposed bending stresses affecting the screws are negligible. In this case, system consideration may be omitted. The structural components must then be examined individually.

As a base for the safety verification report for routine, normal and accidental transport conditions, a consideration of the assembling situation is required, especially for the screws. These calculations may be performed using analytical methods and preferably with the assistance of VDI Directive 2230 [28].

The model of a closing system consists of several lid systems. The model of a lid system should comprise adequate partial models for the lid in itself, the lid screws and the basic body to which the lid is screwed (for primary and secondary lids, the cask body, for small lids the primary or secondary lid). When the stresses and deformations of the corresponding basic body has no influence on the stresses acting on the components of the considered lid system, and when other interactions are negligible, a separate modeling of the lid systems or even of single components may be carried out. In this case, the screwed parts may be reduced to the influence zones of the lid system; areas which are not influenced by events affecting the lid system need not be modeled. Considerations may be limited to a section of the system (e.g. a circular sector), when the symmetry of the lid geometry and the stress permit it.

2.2 Load assumptions

An analysis of the closing systems under routine, normal and accidental transport conditions should especially take into account the sealing forces, the prestress on the screws, the interior pressure and, in case of a quasi static consideration, the inertial forces acting on the closing system. When examining a lid system, the inertial forces are due to the mass of the corresponding lid and to the mass of the contents, whenever direct interaction with the lid is possible. Supplementary stresses may occur, due to interactions between the lid systems or with other components of the package. Here interactions between exterior components of the tight containment (lid or secondary lid when the closing system is designed as a double barrier) and the shock absorber must be especially be taken into account, as they may be the cause of considerable stresses acting on the components of the concerned lid system. In case of a dynamical analysis, a sufficient imaging of the modeling must be assured.

When the load attachment points for transport with a crane are situated on lids (e.g. eye bolts) supplementary stresses acting on the lid system must be expected during transport, due to stresses occurring during handling or fixing of the cask. These supplementary stresses must be taken into account when verifying routine transport conditions.

To calculate the prestresses on the lid screws required for fastening the lid, it is recommended to apply VDI Directive 2230 [28]. In this case, the possible fluctuation of the prestress must be assessed either by determining an adequate tightening factor [28] or directly from the torque tolerance in the tightening process, combined to the fluctuation of the friction coefficients for the used lubricant. The maximum tightening torque (nominal tightening torque plus torque tolerance for the tightening process), coupled to the minimum friction coefficients, must be used to determine the maximum prestress on the screws, whereas the minimum tightening torque (nominal tightening torque minus torque tolerance for the tightening process), coupled to the maximum friction coefficients for the minimum prestress on the screws must be taken into account. The obtained prestresses must be taken into account for the load assumptions when calculating (FE analysis) the lid system for routine, normal and accidental transport conditions.

2.3 Characteristic values of structural materials

Basically, the structural material specifications of structural materials characteristic values used by the applicant, belonging to the safety report, should been taken into account. These characteristic values for structural materials will be demonstrated for the first time within the scope of materials qualification by referring to the minimum values defined in the valid standards. Furthermore, the characteristic values of structural materials must also be partly verified during running production, within the scope of quality assurance.

The difference must be made between characteristic structural materials values at ambient temperature (RT) and operating temperature (T). The operating temperature should be taken from the results of thermal analyses of the cask. For the calculations of the assembling situation, the operating temperature characteristic values should be taken as a conservative approximation.

2.3.1 Structural components

Mechanical characteristic values

In order to assess acting stresses, a realistic model for structural materials should be used, especially for FE analyses. The main component of such a model is Young’s modulus $E(T)$, which must be available for all relevant structural parts. Further characteristic values for structural materials used for assessing the effective stresses must also be verified adequately.

The apparent yielding point at operating temperature $R_{p0,2}(T)$ is the decisive criterion for the demonstration both of the lid and of the screws. It must be available for both components. The tensile strength of the corresponding screw material (bolt thread) $R_{mB}(T)$ and of the screwed parts (nuts or tapped holes) $R_{mM}(T)$ are especially needed to determine a sufficient screwing in depth.

In VDI Directive 2230 [28], the change of prestress is assessed as a function of temperature based on the prestress at ambient temperature. Proceeding in this way, structural material characteristic values at ambient temperature, such as $E(RT)$ or $R_{p0,2}(RT)$ also are interesting.

Interfacial pressure p_G required for the evaluation of surface pressure may be determined by way of simplification according to VDI Directive 2230, Table A9 [28], when more adequate values which can be sufficiently verified through literature indications of experimental data are not available.

Thermal characteristic values

Especially in the case of casks with heat generating contents, the thermal coefficient of expansion α_T for the different structural components of the system under consideration is required for the calculations which become necessary under these circumstances. The thermal coefficient of expansion α_T itself also depends on temperature ($\alpha_T(T)$) and must be verified adequately.

Pairing characteristic values for structural components

To determine prestress fluctuation, minimum and maximum friction coefficients should be taken into account for the corresponding material pairings and lubricants. In this case, the difference between the friction coefficients under the screw’s head (μ_{Kmin} and μ_{Kmax}) and the friction coefficient in the thread (μ_{Gmin} and μ_{Gmax}) must be made. Preferentially, the friction coefficients should be assessed experimentally. Furthermore, the use of sufficiently proven values from literature is admissible if this will assure the conservativeness of the approach [3].

The same applies for the static friction coefficient in the commissure necessary for verifying safety against slippage of the corresponding lid.

If interactions between the closing system and other structural components (e.g. lids with shock absorbers) are taken into account in calculation models, friction coefficients selected for contact definitions within FE models must be adequately justified.

2.3.2 Sheathed barrel core metal gaskets

The assessment of the deformation of the gasket after mounting of the lids under routine transport conditions and after the tests foreseen for normal and accidental transport conditions [17] is based on the characteristic curve of the corresponding gasket. For metal gaskets displaying the same construction principles as the so called Helicoflex® HN gaskets, the difference is made between a deformation and a relief cycle [9] [14] (Figure 2.1).

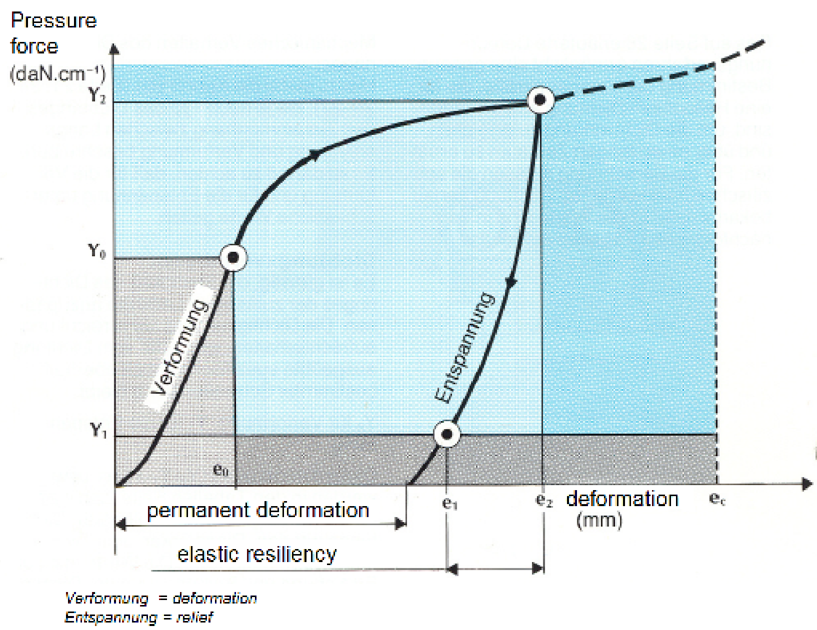

Fig. 2.1: characteristic curve of gasket according to [9]

During the deformation cycle, the gasket remains for the first time below the standard helium leak rate value for pressure force Y_0 and deformation e_0. Deformation may be carried on till critical deformation e_c is reached, above which the gasket may be damaged. The selected working point of the gasket is between these two limit values for pressure force Y_2 and deformation e_2.

During the relief cycle, the sealing capacity (leakage value below the standard helium leak rate) is preserved above pressure force Y_1 and deformation e_1. When pressure force drops below Y_1, leakage rate increases above the specified leak rate.

The helium leak tightness value achieved for gaskets and sealing surfaces taking into account manufacturer specific quality characteristics is defined as the specified standard helium leak rate. For the above mentioned type of gasket it usually will be 10^{-8} $Pa\ m^3/s$ [9]. The optimum gasket working point, which is important for design layout values, is situated at the point (e_2, Y_2). For other types of metal ring gaskets, the specific characteristic sealing graph must be taken as a base for design layout.

In order to evaluate sufficient pressing of the gaskets under testing conditions according to IAEA [17], the characteristic reverse deformation value e_R is defined (2.1), based on the characteristic sealing graph (Fig. 2.1).

$$e_R = e_2 - e_1 \tag{2.1}$$

2.3.3 Elastomere gaskets

When elastomere gaskets are part of the tight containment, a characteristic reverse deformation value e_R may also be defined for this type of gasket. In this case, the total pressing of the gasket is taken for e_R, the diameter of the cord being interpreted as characteristic reverse deformation value e_R taking into account reversible or irreversible deformation parts (residual pressure deformation) [29], the height of the groove being deduced from the aforesaid diameter.

2.4 Assessing effective loads and evaluation of the latter

2.4.1 Solidity of lid screws

Assessing effective strains

The equivalent strain increment necessary for evaluating the solidity of the screws is assessed under assembling conditions from the tensile stress $\sigma_{z,Mon}$ and the torsion stress $\tau_{G,Mon}$ with the reduction coefficient f_M = 1.0 (2.2):

$$\sigma_v = \sqrt{\sigma_{z,Mon}^2 + 3 \cdot (f_M \cdot \tau_{G,Mon})^2} \tag{2.2}$$

For routine, normal and accidental transport conditions, the effective tensile and bending stresses over the axis of the screw are usually assessed by means of the stress distribution σ over the corresponding sections, obtained from the FE analysis. For this, the axial force F and the bending momentum M are calculated by integrating stress distribution σ over the corresponding section for the point of reference on the screw axis under consideration (2.3). A represents the surface of the section, σ the normal stress and s for the lever arm related to the corresponding reference point.

$$F = \iint_A \sigma \, dA \qquad M = \iint_A s \cdot \sigma \, dA \tag{2.3}$$

Based on the axial forces F and the bending momentum M, the tensile and bending stresses (σ_z and σ_b), which have the characteristics of nominal stresses, can now be determined by means of the stressed cross section A_s and the section modulus W (2.4).

$$\sigma_z = \frac{F}{A_s} \qquad \sigma_b = \frac{M}{W} \tag{2.4}$$

	Assembly	*Routine, normal and accidental transport conditions*	
Primary lid, secondary lid, small lids with stress caused by contents	$\sigma_v \leq \frac{R_{p0,2}(RT)}{1,5}$	$\sigma_v \leq \frac{R_{p0,2}(T)}{1,1}$ $\sigma_z \leq \frac{R_{p0,2}(T)}{1,5}$	$\sigma_v \leq R_{p0,2}(T)$ $\sigma_z \leq \frac{R_{p0,2}(T)}{1,1}$ $\sigma_z \leq \frac{R_{p0,2}(T)}{1,5}$[1]
Small lids without stress caused by contents	$\sigma_v \leq \frac{R_{p0,2}(RT)}{1,1}$	$\sigma_v \leq \frac{R_{p0,2}(T)}{1,1}$ $\sigma_z \leq \frac{R_{p0,2}(T)}{1,1}$	$\sigma_v \leq R_{p0,2}(T)$ $\sigma_z \leq \frac{R_{p0,2}(T)}{1,1}$

Table 2.1: Criteria for evaluation of stresses acting on lid screws

For routine, normal and accidental transport conditions, the nominal equivalent strain increment is assessed similarly to equation (2.2) with the factor f_M = 0.5, according to [28] (2.5).

$$\sigma_v = \sqrt{(\sigma_z + \sigma_b)^2 + 3 \cdot (f_M \cdot \tau_{G,M\,on})^2} \tag{2.5}$$

As a rule, the FE modeling of the screws is highly idealized (e.g. simplified modeling of the thread). For this reason, these nominal stresses are used for the following evaluation instead of the local stresses from the FE analyses. This procedure allows for evaluation based on the criteria of VDI Directive 2230 [28].

Evaluation of stresses

The evaluation criteria for stresses are given in Table 2.1. Deviations from the mentioned limit values for assembling are permissible for single justified cases, when the criteria for routine, normal and accidental transport conditions have been fulfilled. For the screws of small lids, which are not submitted to supplementary stresses due to the acting content masses, smaller safety factors may also be used. They must however be justified accordingly.

As a general rule, under accidental transport conditions, the maximum value of the equivalent strain increment should fulfill the criterion $\sigma_v \leq R_{p0,2}(T)$ (Table 2.1). When this criterion is not fulfilled for justified exceptional cases, on must assume a plastic residual deformation of the screws after the accident. Thus, in this case, a supplementary demonstration is required, according to which, after the accident, the screws

[1] Supplementary criterion for screws of solidity class 10.9:
The tensile strength of screws of solidity class 10.9 is less favorable than e.g. that of screws of solidity class 8.8. They thus also have a lower deformation capability [30]. Thus, when using screws of solidity class 10.9, another limit value for the average tensile strength applies, which must be justified in the eyes of BAM,

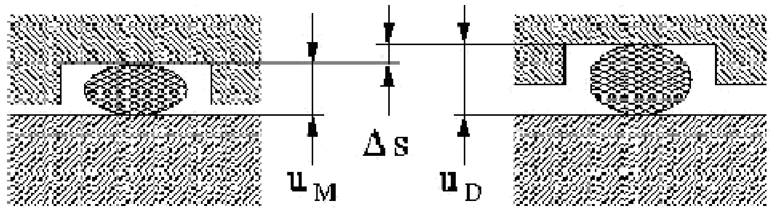

Figure 2.2: Distance between the sealing surfaces during assembly and under stress (at the position of the gasket rings)

continue to secure a sufficient pressure on the gasket to assure helium tightness. An elastic plastic material behavior of the structural screw material must basically be assumed for the required verification of the accidental shock phase based on calculations. During the following simulation of relief after the shock, the sealing force and the maximum operating pressure are assumed to be the exterior stress acting on the lid. Evaluation of the sealing function is performed according to the conditions prevailing in 2.4.2. Screws of solidity class 10.9 are exempted from this rule, due to a disadvantageous tensile strength, and must always fulfill the criteria set forward in Table 2.1.

2.4.2 Pressing of the gaskets

The minimum screw prestress $F_{M,min}$ assessed under the conditions set forward in Section 2.2 must assure sufficient pressing of the gaskets, that is the seat of the lid so as to assure tightness, even when taking into account the setting behavior. Assembly so as to assure tightness must assure that the working point given by the gasket manufacturer for the corresponding gasket (e_2, Y_2, Fig. 2.1) is achieved geometrically.

A slight spring-back of the gasket, depending on the corresponding rigidity of the lid, may occur already under assembling conditions within the scope of detailed FE analyses. This spring-back is due to the fact that the gasket and the screws are arrayed on different partial circle diameters on the one hand and on the other, to local deformations under linear charging. For example it may be read from the FE analysis of the assembling conditions, based on the distance between knots in the gasket area.

Assessment of spring-back under load conditions

Spring-back Δs under routine, normal and accidental transport conditions may be considered geometrically as the calculated distance of the sealing surfaces under load condition u_D (Fig. 2.2), related to the calculated distance between the sealing surfaces after the assembling of the lid so as to assure tightness u_M (equation 2.6), when it can be proved that u_M is justified through calculations or modeling effects. If this is not the case, then the spring-back Δs may conservatively only be assessed by means of u_D minus the depth of the groove, the aforesaid groove depth representing the geometrical distance between the sealing surfaces after assembling so as to assure tightness.

$$\Delta s = u_D - u_M \tag{2.6}$$

Evaluation of the spring-back under load

The evaluation of the spring-back under load is performed with assistance of the criterion (2.7) according to which the admissible spring-back of the gasket, Δs is limited taking into account the minimum scres prestress $F_{M,min}$. The safety factor two contained in (2.7) related to the actually useful elastic spring-back until the tightness criterion is infringed (characteristic reverse deformation value e_R, cf. Section 2.3.2), may also be taken smaller if the statistical assurance of the basic data set for the gaskets used in each case is sufficient.

$$\Delta s \leq \frac{e_R}{2} \tag{2.7}$$

During the load phase, criterion (2.7) is valid both under routine and under normal and accidental transport conditions. If this criterion is infringed for normal or accidental transport conditions, after relief, an increased leak rate as compared to the standard helium leak rate required in Section 2.3.2 must be taken into account for release considerations.

After relief, a sufficient pressing of the gasket must be assumed when the screw only suffered elastic deformations. If a plastic deformation of the screw occurs exceptionally during the shock phase under normal or accidental transport conditions, a supplementary calculation must be performed which will also take into account elastic-plastic material laws (cf. Section 2.4.1). It must be assured that criterion (2.7) will be observed again after relief.

Fulfilling the spring-back criterion (2.7) is a necessary condition for the observance of the required standard helium leak rate according to Section 2.3.2. However, the sealing effect and thus the leak rate to be assumed for release considerations may be subject to further influences which cannot be assessed by calculations, e.g. surface structure of the sealing system partners. Thus, as a rule, the deduction of leak rates for release considerations will require the introduction of supplementary results from drop tests and, if necessary, from structural components tests.

A possible impairment of sealing effect due to lateral slipping of the lid (e.g. in case of a drop with horizontal cask axis, cf. also Section 2.4.6) must be considered separately and must also be taken into account accordingly for release considerations.

2.4.3 Surface pressure

Assessing effective surface pressure

Due to the superimposed bending stress acting on the screws, assumptions going beyond those required in VDI Directive 2230 [28] will apply when assessing the effective surface pressure. Based on stresses σ_z and σ_b determined as a result of the analyses (described in Section 2.4.1), an effective surface pressure is calculated using equation (2.8):

$$p_{max} = \frac{(\sigma_z + \sigma_b) \cdot A_s}{A_p} \qquad (2.8)$$

Stresses σ_z and σ_b multiplied by the stressed cross section A_s of the screw yields the axial screw force, taking the bending stress into account. Surface pressure is obtained dividing through section A_p, which is relevant for the surface pressure and represents the bearing area of the screw head according to VDI Directive 2230 [28].

Evaluation of surface pressure

Surface pressure is critical for creep and permanent stress [28]. Thus, evaluation only is meaningful for assembling and routine transport conditions (2.9). For the determination of limit surface pressure $p_G(T)$, reference is made to Section 2.3.1.

$$p_{max} \leq p_G(T) \qquad (2.9)$$

2.4.4 Screw-in depth

Assessing required screw-in depth

A screwed connection should be designed so that in case of overload, failure and break will occur in the free loaded thread or in the shaft, and that there will be no stripping of the intermeshing threads of screw and nut or tapped hole. To achieve this, the required screw-in depth l_{erf} must be determined through purposeful adaptation of the loading capacities of the single areas of screw and nut during design. Calculating assumptions will be taken e.g. from VDI Directive 2230 [28]. The required screw-in depth can also be defined on the base of sufficiently representative test results.

Evaluating screw-in depth

The evaluation of the screw-in depth l_{Gew} assessed on the base of drawing indications will be performed on the base of equation (2.10), which must be valid. Thread countersinks must be taken into account for the calculation of l_{erf} or for the assessment of l_{Gew} dependent on the approach used for calculations.

$$l_{Gew} \geq l_{erf} \tag{2.10}$$

When proving the carrying capacity, it must be shown that the smallest carrying capacity will occur in the free loaded thread or in the shaft.

2.4.5 Solidity of the lids

Assessing effective strains

To perform the FE analyses for the lid system, which will be necessary as a rule, the distribution of strains in the lid may also be evaluated. In exceptional cases, e.g. for simple lid geometries, it is admissible to resort to analytic solution methods within the scope of separate calculations, such as found in the plate theory [2] [31].

Evaluating strains

The evaluation of lid strains must be performed separately for steel and cast iron, because to this date, for each group of structural materials, data bases assured differently according to safety relevant aspects are available. The integrity of the lid is considered to be proved when the criteria of equation (2.11) or of equation (2.12) for the maximum bending stress $\sigma_{b,max}$ are fulfilled. If these criteria are not fulfilled, a supplementary verification for mechanical fracturing properties, which is not part of this guideline, must be performed. For cast iron, the *Guideline for the Utilization of Cast Iron with Nodular Graphite for Transport and Storage Casks for Radioactive Materials (GGR 007)* [5] must be taken into account.

$$\sigma_{b,max} \leq \frac{R_{p0,2}(T)}{1,5} \quad \text{for forged steel} \tag{2.11}$$

$$\sigma_{b,amx} \leq \frac{R_{p0,2}(T)}{2} \quad \text{for ductile cast iron} \tag{2.12}$$

2.4.6 Slipping of lids

Assessing effective forces

When the lids slip in radial direction, an impairment of the sealing capacity and thus a modified leak rate must be reckoned with.

To assess the effective forces under routine transport conditions, the corresponding accelerations must be taken into account next to the interior pressure. Attachment V of the *IAEA Safety Guides* [18] gives an overview of the acceleration values which must be assumed for road, rail, water and air transports. For road, rail and water transports, the acceleration values of ISO/TC85/SC5/ WG9 [20] may also be used.

If the effects are not being analyzed within the scope of a dynamic analysis, the corresponding accelerations during normal and accidental transport conditions prevailing during the shock phase must be used. Interactions between the lid and other components of the package during this phase must also be taken into account.

The accelerations for the considered load cases under routine, normal and accidental transport conditions constitute the base for the inertial force F_T of the lid which must be assessed. For this, only the radial components of the accelerations will be considered.

The axial components of accelerations and the interior pressure will act as operating forces on the screws. The resulting clamping force F_N may be obtained e.g. from the FE analysis through evaluation of the nodal forces in the separating groove. The frictional force F_R (2.13) is obtained together with the minimum static friction coefficient μ between lid and basic body.

$$F_R = \mu \cdot F_N \tag{2.13}$$

Evaluating forces

The slippage of the lids in transport position of the packages must be excluded under routine transport conditions. It is considered that sufficient safety against slippage has been demonstrated when the frictional force resulting under minimum prestress of the screws, taking into account the setting behavior, is greater or equal to the inertial force (2.14). Verification may then be carried out without supplementary safety factor.

$$F_R(F_{M,min}) \geq F_T \tag{2.14}$$

If condition (2.14) is not fulfilled for normal and accidental conditions, slippage of the lid cannot be excluded. This slippage must be taken into account for the release considerations, related to a possibly modified leak rate due to this.

2.4.7 Further verifications

It is required in paragraph 612 of the IAEA recommendations that the package will resist accelerations, oscillations or oscillation resonances which may occur under routine transport conditions without impairment of the effectiveness of the closing systems [17]. When loads under routine transport conditions cause strains which are in this respect relevant from the point of view of safety technology, further verifications will be required, which are, however, not considered in this guideline. The demonstration that no unforeseen loosening of closing media may occur, also required in paragraph 612 [17], is fulfilled for the lid screws through the demonstration that no slippage of the lid can occur (Section 2.4.6) [19].

Demonstration of solidity of the screws of lid systems under operating conditions only will be required if the load attachment points foreseen for crane handling of the cask are situated on the lid. As far as load assumptions, proof procedure and evaluation criteria are concerned, the definitions indicated in Sections 3.2.3 and 3.4.4 will be valid in this sense.

3 Load attachment systems

The load attachment system (LAS) assures the handling of the cask and its components and frequently also the fastening of the cask on board the transport medium. This guideline restrictedly only considers screwed load attachment systems.

The main component of a load attachment system id the load attachment point (LAP), which according to [22] is defined as connecting element between load suspension devices and load (refer to [10] for definitions of load suspension devices and load). Further LAS components are, among others, the screws for fastening the LAP and the corresponding nuts or tapped holes. Thus, in the sense of this guideline, a screwed trunnion system consists e.g. of the trunnion, the trunnion screws and the cask body which, as a rule, contains the nut thread. Further examples for LAS in the sense of this guideline are, next to the mentioned screwed trunnion systems for handling, and also foreseen to fasten the cask during transport, also grappling and lifting mushroom structures for the safe handling of a lid.

In this guideline, stresses on the load attachment systems caused by handling and transport are considered. As far as handling is concerned, a difference is made between transport using a crane within nuclear plants and load transfers during transports over public paths. Furthermore, transport induced stresses on the load attachment systems occur when the LAS are used to fasten the package on board the transport vehicle.

Due to this, the layout of load attachment systems must on the one hand fulfill the requirements of legal traffic regulations related to transfers and transport stresses and on the other hand and related to handling within nuclear plants, the requirements put forward by the operator of the considered nuclear plant. These requirements will cover in each case verifications for assembly and routing transport conditions (legal traffic regulations), as well as a general verification of solidity and such a verification related to operation for utilization of the cask within nuclear facilities.

The requirements must be considered superimposed within the scope of the layout conditions for the corresponding load attachment system. This will require verifications for assembling conditions, for general solidity and for operating solidity, for which requirements according to legal traffic regulations as well as to the operating of nuclear facilities must be taken into account.

Especially as far as the demonstration of operating solidity is concerned, the demonstration presented here constitutes an extension of the nominal strain concept of KTA Directive 3905 [22] concerning the evaluation of local strains resulting from an FE analysis ([22] Attachment H4).

If load attachment points on lids are used for the handling of the cask or for fastening it during transport, the effects of the supplementary stresses on the load screws and on the closing system must also be taken into account. For this, the corresponding indications found in Chapter 2 of this guideline must be used.

3.1 Calculating methods and modeling

Should considering the total load attachment system be necessary for the layout of the load attachment point (LAP) according to requirements, e.g. in order to take into account interactions between the individual structural components, the examination of the LAP system will, as a rule, require an analysis according to the finite element method. In this case and in the presence of a screwed trunnion system, the modeling of the LAS should comprise for example at least the trunnions, the trunnion screws and the screwed parts. Screwed parts may be reduced to the zones of influence of the LAS: areas which can be proved no to be affected by the processes occurring at the LAS need not be modeled.

A consideration of the assembling conditions only is required for the LAS screws. This verification may be performed based on VDI Directive 2230 [28].

For routine transport and handling conditions, a supplementary demonstration of operating solidity will be necessary, next to the general verification of static solidity.

The demonstration of operating solidity may be performed analytically. In this case, the linear hypothesis of damage accumulation according to Palmgren-Miner, which is the base for the Miner rule (3.1) [16], should be used preferentially.

$$D = \sum_i \frac{n_i}{N_i} \tag{3.1}$$

The individual mean group strain values are approximated by means of step graphs with step frequency h_i and corresponding step stress σ_{ai}. After K mean group value passes, $n_i = K \cdot h_i$. N_i is a function of the corresponding deflecting stress σ_{ai} and the corresponding mean stress σ_{mi}; it is calculated by means of the solidity versus time straight lines of the corresponding stress-cycle diagram. On thus obtains the total damage D suffered by the structural component.

When LAPs are operated within nuclear facilities, thus being submitted to increased or supplementary requirements according to KTA Directive 3905 [22] (KTA conditions), the elementary Miner rule (linear damage accumulation for a continuous stress-cycle diagram, represented on a log-log scale) must be used [22]. When the admissible Miner sum is the same, the results according to the elementary Miner rule will be on the safe side [16].

This method also may be recommended with a corresponding adaptation of load assumptions when no KTA requirements must apply obligatorily.

3.2 Load assumptions

3.2.1 Assembling

When determining the prestress for the screws of an LAS, load assumptions according to Section 2.2 of this guideline should be assumed, based on VDI Directive 2230 [28]. In this case, the possible fluctuation of the prestress should be determined either through the fixing of an adequate tightening factor according to [28], or directly from the tolerance for the tightening torque, related to the fluctuation of the friction coefficients for the used lubricant. The maximum tightening torque (nominal tightening torque plus tightening torque tolerance for the tightening process), coupled with the minimum coefficient of friction, must be assumed when determining the maximum prestress force of the screws, whereas the minimum tightening torque (nominal tightening torque minus the torque tolerance for the tightening process), coupled to the maximum coefficient of friction for the minimum screw prestress force, must be taken into account. In the following, the obtained prestress forces should be taken into account for load assumptions, among others for the FE analyses of the LAS.

3.2.2 General stress verification

To determine the load which is relevant for the general stress verification, y description of the load covering the different transport and handling situations for the cask or for the corresponding component must be available. In this case, supplementary stresses for crane transports in nuclear facilities must be taken into account through flooding of the cask (wet load). However, different stresses may result from a change of the intrinsic weight of the cask (handling without shock absorbers, partial loading with radioactive inventory among others).

In case of handling with a crane, the thus assessed stress must be multiplied by a lifting load coefficient, for safety reasons. The lifting load coefficient is a function of the safety stage of the handling zone. Thus, special lifting load coefficients will apply within the area of nuclear facilities (increased and supplementary requirements according to KTA Directive 3905 [22]), containing supplementary safety factors on the one hand and considering higher requirements towards crane systems in this area on the other. When the LAPs are used not only for handling with a crane, but also for fastening on board the transport vehicle, a stress coefficient may also be defined for transport on public paths. The stress coefficients which must be used are summarized in Table 3.1

Classification of the handling area	*Stress coefficient*
KTA 3905 [22], Section 4.3 (increased requirements)	1.8
KTA 3905 [22], Section 4.2 (supplementary requirements)	1.35
Crane transport without KTA classification	1.45
Public transport	2.0

Table 3.1: stress coefficients

The indicated lifting load coefficient of 1.45 for crane transports without KTA classification covers all transports with cranes of lifting classes H1 till H4 according to DIN 15018 Part 1 [11]. When the LAP is used during public transport for fastening the load on the transport vehicle, a load coefficient of 2.0 must be taken into account, based on ISO/TC85/SC5/WG9 [20].

As a rule, the load is sustained through several LAP, so that the load distribution on the single LAPs must be taken into account [22].

3.2.3 Verification of operating solidity

Operating solidity must be verified for the LAP, also for the corresponding screws, when the number of stress cycles exceeds $2 \cdot 10^4$ [22].

A mean group stress value for an operating stress comprises the stress values and the number of corresponding stress cycles. The stress values of a mean group value stage are the maximum and the minimum stress, which oscillate around a mean stress value. A stress cycle consists of the running through the stress-time graph, starting e.g. at the maximum stress value, until this value is reached again. Stress amplitude is the distance between maximum and mean stress, or the distance between mean and minimum stress. Operating load usually consists of several mean group stress values, which in turn display different stress values and cycles.

Crane handling

The number of stress cycles for crane handling may - and must under KTA conditions - be calculated on the base of stress work cycles, according to the indications of KTA Directive 3905 [22], a stress works cycle U being the process between lifting and setting down of the load. The number of shifting operations Z_{Sch} and the number of stress cycles due to a shifting operation k_a makes the number of stress cycles N_{Kran} accessible over Equation 3.2.

Type of load	*dynamic*	*varying*
Stress cycles	1	$N_{Kran}/U - 1$
increased requirements	0 … 1.8[2]	0.55 … 1.45
supplementary requirements	0 … 1.35	0.65 … 1.35
without KTA classification	0 … 1.45	0.55 … 1.45

Table 3.2: minimum and maximum stress coefficients for one stress work cycle during handling

$$N_{Kran} = U \cdot Z_{Sch} \cdot k_a \tag{3.2}$$

When defining Z_{Sch}, the KTA directive makes a difference between lifting gear with or without precision lifting device [22]. As radioactive material transports are carried out all over the world, the use of lifting bear with precision lifting device cannot be assumed in every case. For this reason, either conservative assumptions are required, or corresponding requirements must be stated in the operating and maintenance manuals.

Stress cycles per stress work cycle may be subdivided in a threshold and an alternating stress. The threshold stress is representative for lifting and setting down, thus acting through a stress alternation. The other stress cycles are alternating stresses, caused by oscillations during the transfer of the load between lifting and setting down (Table 3.2).

Table 3.2 shows the stress coefficients which must be used, which must be multiplied by the stress values assessed according to the indications in Section 3.2.2.

The stress coefficients without KTA classification correspond to DIN 15018 Part 1 [11]. For load attachment points subject to supplementary requirements according to Section 4.2 of KTA Directive 3905 [22], the stress coefficient are approximately 1.35 for dynamic stresses and, derived on the base of experimental investigations [4], 1.0 ± 0.35 for alternating stresses.

For increased requirements according to Section 4.3 and Attachment H(6) to KTA Directive 3905 [22], a supplementary redundancy factor of 1.25 must be assumed, related to DIN 15018 Part 1 [11], if no component which may fulfill the foreseen function (secure holding of the load) is available in case of failure. This will be the case e.g. when a cask is lifted by the lid end, using the two trunnions fixed near the lid. In this case, a stress coefficient of 1.8 must be used for dynamic stress. Alternately, the redundancy factor may also be considered as a supplementary safety factor for the evaluation of stresses. In this case, stresses may be multiplied by the smaller stress coefficient 1.45.

[2] Redundancy factor taken into account

It is also possible to use experimentally assessed stress coefficients. However, within the KTA area, values assessed by this method must be multiplied by the safety factors 1.12 for supplementary requirements and 1.25 for increased requirements [22]. Outside the KTA area, a safety factor based on the statistical precision of the measurement results must be selected.

Covering everything, the operating solidity verification may also be performed as mean group single stage stress value with the maximum value of the dynamic stress.

Transport

As it is not possible to define universally valid mean group stress values for transports, these must be assessed for the casks corresponding to each case, based on planned transports. Both the type of transport (road, rail, water or air) and the length and number of transports must be taken into account for this. If cask transports are carried out under conditions (transport route, transport medium) which are not covered by the safety verification, new or supplementary operating solidity verifications will be necessary.

For mean group transport values, reference may also be made to published measurements [8] [12] [24] [25], next to own verification values obtained empirically. In this case, transfers to other design structures or transport routes, as well as taking into account measurement errors may require the utilization of supplementary safety factors for the operating solidity verification.

3.3 Characteristic structural material values

Basically, the indications given in Section 2.3 also are valid for the LAS.

Structural material characteristic values at room temperature may be assumed when considering assembling conditions for LAS (e.g. $R_{p0.2}(RT)$). Under operating conditions, the operating temperature determined during thermal analysis must be used as a base value (e.g. $R_{p0.2}(T)$).

The assessment of the Wöhler-lines for structural parts required for the verification of operating solidity usually requires a great effort. For this reason, synthetic Wöhler-lines may also be used for the verifications. The synthetic Wöhler-lines suggested in different guidelines may, however, not be exchanged, as they are frequently related to the corresponding calculating procedures and, especially, to the used safety factors. The synthetic Wöhler-lines recommended in this guideline are explicitly mentioned related to the corresponding verification: the synthetic Wöhler-lines used for the verification of operating safety of the trunnions are those taken from FKM Directive [13] and, for the operating solidity verification of the trunnion screws, from VDI Directive 2230 [28].

Wöhler-lines for structural components assessed experimentally shall be used preferentially when a safety factor adapted to the statistical basic data collection has been foreseen.

3.4 Assessing effective loads and evaluation of the latter

3.4.1 General solidity of load attachment points

Assessing effective stresses

When the complexity of the introduction of stresses, of the geometry or of the interactions to be taken into account require this (e.g. in the case of trunnions), the general stress verification for the LAP is performed with the assistance of local stresses. A demonstration with nominal stresses will no longer be sufficient in this case. The local distribution of the effective stresses in the LAP must then be assessed by means of FE analyses or other adequate methods of calculation.

The evaluation of stresses must be based on the comparative stress according to the hypothesis of the energy of change of form (generalized strain increment according to von Mises) at the point of maximum strain.

Evaluation of stresses

The evaluation of comparative stresses is performed based on the nominal stress concept of KTA 3905 [22] (cf. Attachment H4 there) and taking into account the requirements of Regulations for the Prevention of Accidents VBG 9a [26].

If equation (3.3) holds for the maximum shearing stress (maximum nominal stress when demonstration is performed using nominal stresses), general stress demonstration is assumed to have been performed [22].

$$\sigma_v \leq \frac{R_{p0,2}(T)}{1,5} \tag{3.3}$$

If during the demonstration using local stresses, the maximum shearing stress exceeds the value of $R_{p0.2}(T)/1.5$, remaining, however, below $R_{p0.2}(T)$, the demonstration may also be carried out as demonstration of carrying stresses, with an excess of stresses by a factor 2.25. The stress coefficients given in Table 3.3 must be used in this case. The stress coefficient determined there for supplementary requirements according to KTA Directive 3905 corresponds to the requirements put forward in the performing instructions of Rules for the Prevention of Accidents VGB 9a [27]: for load suspension means submitted to a stress coefficient of 3.0, no total plasticizing of the carrying section may occur.

Classification of the handling zone	*Stress coefficient for the demonstration of carrying stress*
KTA 3905 [22] Section 4.3 (increased requirements)	4.0
KTA 3905 [22] Section 4.2 (supplementary requirements)	3.0
Crane transport without KTA classification	3.25
Public transport	4.5

Table 3.3: stress coefficients for carrying stress verification

Carrying stress verification for the LAP must be performed based on local stresses. In this case, a perfectly plastic elastic material model with the value $R_{p0,2}$ as yield stress must be used as a base for the load attachment system, including the screws. The criterion for fulfilling the safety requirements is a non complete plasticizing of the section relevant for carrying capacity: at least one section at which $\epsilon_{pl} = 0$ must exist along a cut through the load attachment point section submitted to the highest stress, ϵ_{pl} being the plastic proportion of the comparative extension according to von Mises.

3.4.2 Operating solidity of load attachment points

Assessing effective stresses

Effective stresses must be taken from the analyses for the different stress assumed according to Section 3.2.3. For this, the point submitted to the highest strain must be evaluated taking all assumed stresses into account.

When calculating the load attachment system using FE analyses, due to nonlinearities contained in the model (contact conditions), the resulting stresses are frequently not proportional to the load lifted in each case. The results of calculations for different stress coefficients are thus not accessible through linear interpolation of the results of FE analyses.

The following stress cases must be examined:

- handling, stress cases with $R = 0$
- handling, stress cases with $R \neq 0$
- transport, stress cases with $R \neq 0$

The stress relation R is defined as the relation between minimum stress σ_u and maximum stress σ_0. A separated calculation must be performed for the corresponding maximum and minimum stress for each stress case of the mean group value.

$$R = \frac{\sigma_u}{\sigma_o} \tag{3.4}$$

Evaluation of effective operating stress

According to the FKM Directive [13], the evaluation of the effective operating stress should be performed taking into account the suggested synthetic Wöhler graphs, the safety factors and the admissible Miner sums.

The experimental assessment of the Wöhler-lines for structural parts usually requires a great effort. For this reason, synthetic Wöhler-lines may also be used according to the FKM Directive (cf. also Section 3.3). Break point cycle numbers N_D and slope exponents k for the construction of synthetic Wöhler graphs are found in Table 4.4.4 of the FKM Directive [13].

Safety factor j_{erf} required for the definitive determination of the Wöhler graph is based on the safety coefficients of 2.0 for supplementary and of 2.5 for increased requirements according to KTA 3905 [22]. However, these safety coefficients are based on a probability of survival of 50 %, as compared to 97.5 % for the values of the FKM Directive. Thus, when calculations are performed according to the FKM Directive, the safety coefficients indicated by the KTA Directive may be reduced. Assuming an average logarithmic standard deviation of σ_{lgS} = 0.04, Table 5.11.1 of the FKM Directive [13] yields a statistic transformation factor of 1.2, so that the safety coefficients may be adapted with the assistance of Equation (3.5).

$$j_{erf} = \frac{j_{KTA}}{1,2} \tag{3.5}$$

One thus obtains the safety factors of Table 3.4 for the KTA area. In the absence of KTA classification, the safety factor of the FKM Directive, Table 4.5.1, should be selected for the case of regular inspections and high damage sequence. If the redundancy factor for increased requirements according to KTA Directive 3905 [22] has not been taken into account for the assumed stresses (stress coefficient 1.45 according to Section 3.2.3), a safety coefficient of 2.1 · 1.25 = 2.6 must be assumed for non redundant structural components.

The admissible Miner sum D_M, which is required for the actual demonstration of operating solidity, varies as a function of the manufacturing method and of the group of structural materials, and must be selected according to the indications of FKM Directive, Table 4.4.3 [13].

Classification	
increased requirements according to KTA 3905 [22]	2.1
supplementary requirements according to KTA 3905 [22]	1.7
general requirements according, public transport	1.35

Table 3.4: safety coefficients for the verification of operating solidity of load attachment points

3.4.3 General solidity of load attachment system screws

Assessing effective stresses

The effective stresses on the screws of load attachment systems are assessed as described in Section 2.4.1. Thus, the equivalent strain increment under assembling conditions is calculated according to Equation (2.2), the result being $f_M = 1.0$. For routine and normal transport conditions, Equation (2.5) is valid, with $f_M = 0.5$. In this case, σ_z and σ_b should be assessed by means of Equations (2.3) and (2.4), according to the method described in Section 2.4.1.

Evaluating stresses

The criteria for mounting and handling are summarized in Table 3.5. Under KTA conditions, Equation (3.6) must also be taken into account for handling [22]. Verification is required both for the minimum and for the maximum screw prestress force.

$$\sigma_z - \sigma_{z,Mon} \leq 0.1 \cdot R_{p,02}(T) \tag{3.6}$$

The safety factors under KTA conditions are obtained from KTA Directive 3905 [22].

	Assembling	*Routine transport conditions: handling*
with KTA conditions	σ_v - $\leq 0.7 \cdot R_{p,02}(RT)$	$\sigma_v \leq R_{p,02}(T)$
without KTA conditions	σ_v - $\leq 0.9 \cdot R_{p,02}(RT)$	$\sigma_v \leq R_{p,02}(T)$
public transport	σ_v - $\leq 0.7 \cdot R_{p,02}(RT)$	$\sigma_v \leq R_{p,02}(T)$

Table 3.5: Criteria for evaluating of stresses on the screws of load attachment systems.

Outside the KTA area, the definition of VDI Directive 2230 [28] may be used, related to assembling conditions.

When a carrying load definition according to Section 3.4.1 is required for the LAP, the screws will be modeled using a perfectly plastic elastic material. $R_{p0,2}(T)$ will be used for yielding point value. It must be demonstrated that a total plasticizing of the screw submitted to maximum stress will not occur.

3.4.4 Operating solidity of load attachment system screws

Assessing stress cycles and effective stresses

Assessing stress cycles and effective stresses will be done as described for the load attachment points in Section 3.4.2. For this, all deflecting stresses of the screws linearized over the cross section will be taken into account according to Section 2.4.1.

Evaluating effective operating stress

The verification of operating solidity of the screws of load attachment systems may be carried out on the base of the assumption of linear damage accumulation (3.1) combined with VDI Directive 2230 [28].

The synthetic Wöhler line will be determined using VDI Directive 2230 [28]. For this, the breaking point cycle number N_D indicated there will be used and the permanent solidity σ_{ASG} for screws which were finished by rolling or σ_{ASV} for screws finished by hardening and tempering must be calculated accordingly.

The required safety factor S_D must be selected according to KTA classification and is given in Table 3.6. When the factor of redundancy must be used and has not been taken into account for the stress assumptions, a safety factor $2.5 \cdot 1.25 = 3.1$ will be used for the increased requirements according to KTA Directive 3905 [22].

The admissible Miner sum and which must be assumed accordingly in every case for the evaluation must be sufficiently justified, e.g. using [20] [21].

Classification	
Increased requirements according to KTA 3905 [22]	2.5
Supplementary requirements according to KTA 3905 [22]	2.0
Outside KTA area	1.5

Table 3.6: safety coefficients for the demonstration of operating solidity of load attachment system screws

Register of formulae symbols

A	cross section area
A_p	head bearing area [28]
A_s	stressed cross section of a screw
D	total damage to the structural component according to Palmgren-Miner
D_M	admissible Miner sum
$E(RT)$	Young's modulus at ambient temperature
$E(T)$	Young's modulus at operating temperature
F	axial force
$F_{M,min}$	minimum screw prestress force
F_N	clamping force
F_R	friction force
F_T	inertial force
K	number of mean group value cycles
M	bending momentum
N_D	number of breaking point cycles of the Wöhler graph
N_i	number of admissible stress cycles for $j_{erf} \cdot \sigma_{ai}$
N_{Kran}	number of stress cycles for crane handling
R	stress ratio
$R_{mB}(T)$	tensile strength of the structural screw (bolt) material at operating temperature
$R_{mM}(T)$	tensile strength of the structural nut material at operating temperature
$R_{p0,2}(RT)$	0.2 % offset yield stress at ambient temperature
$R_{p0,2}(T)$	0.2 % offset yield stress at operating temperature
S_D	safety coefficient for the permanent solidity of screws
U	number of stress work cycles for crane handling
W	section modulus
Y_0	force of pressure (line load) as of which, for a first stress applied within the deformation cycle, leak rate remains below the required standard helium leak rate
Y_1	force of pressure (line load) above which, within the relief cycle, leak rate remains below the required standard helium leak rate
Y_2	force of pressure (line load) at the optimum working point
Z_{Sch}	number of shifting operations when handling with a crane

e_0	deformation at pressure force (line load) Y_0
e_1	deformation at pressure force (line load) Y_1
e_2	optimum deformation path at pressure force (line load) Y_2
e_c	deformation as of which the gasket is damaged
e_R	reverse deformation characteristic value
f_M	factor for taking into account torsion stress
h_i	number of stress cycles for step i (step frequency) of a mean group stress value
j_{erf}	required safety coefficient
j_{KTA}	safety coefficient according to [22]
k	slope exponent of the Wöhler graph
k_a	number of stress cycles due to a shifting operation during crane handling
l_{erf}	required screw-in depth
l_{Gew}	effective screw-in depth
n_i	total number of stress cycles for stage i
p_G	limit surface pressure [28]
$p_G(T)$	limit surface pressure at operating temperature
p_{max}	effective surface pressure
s	lever arm to point of reference
Δ_s	spring-back
u_D	distance between sealing surfaces under stress
u_M	distance between sealing surfaces under assembling conditions
α_T	thermal expansion coefficient
$\alpha_T(T)$	thermal expansion coefficient at operating temperature
$\in_p l$	plastic portion of reference expansion according to von Mises
μ_{Kmin}	minimum friction coefficient at the screw head
μ_{Kmax}	maximum friction coefficient at the screw head
μ_{Gmin}	minimum friction coefficient in the thread
μ_{Gmax}	maximum friction coefficient in the thread
μ	static friction coefficient in the commissure
σ	normal stress
σ_{ai}	deflection stress of stage i
σ_{ASG}	permanent solidity of screws finished by rolling [28]
σ_{ASV}	permanent solidity of screws finished by hardening and tempering [28]
σ_b	bending stress
$\sigma_{b,max}$	maximum bending stress in the lid
σ_{lgS}	mean logarithmic standard deviation [13]
σ_{mi}	mean stage i stress
σ_0	maximum stress
σ_u	minimum stress
σ_v	reference stress according to the hypothesis of the energy of change of form (von Mises stress)
σ_z	tensile stress
$\sigma_{z,Mon}$	tensile stress of screw under assembling conditions
$\tau_{G,Mon}$	torsion stress due to tightening of the screw

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