ELEKTROTEHNIŠKI VESTNIK 82(5): 225-232, 2015
ORIGINAL SCIENTIFIC PAPER

# Special large power transformer design for railway transportation

**Roman Žičkar**

*Siemens AG, Energy Management, Overbeckstr. 44, 01139 Dresden, Germany*
*E-mail: roman.zickar@siemens.com*

**Abstract.** The paper describes a procedure for creating the main design of power transformers made for transport by the Schnabel wagon, based on the principles of methodical construction, with a special focus on the statics calculated by using the classical method as a main prerequisite for adequately employing the FEM software when optimising this demanding welded construction.

**Keywords:** Schnabelwagon, Gage tank, Brückenmittelstück, Käfigkessel, DB-Richtlinie 951.0010

### Konstrukcija posebnega veliko-močnega transformatorja, namenjenega železniškemu prevozu

V članku je opisan postopek izdelave glavne konstrukcije veliko-močnega transformatorja, ki je namenjen prevozu z vagonom »Schnabel«. Postopek temelji na načelih metodične konstrukcije s poudarkom na statiki, ki je preračunana z uporabo klasične metode. Ta je glavni predpogoj za pravilno rabo programske opreme na podlagi končnih elementov (FEM) pri optimizaciji te zahtevne varjene konstrukcije.

## 1 INTRODUCTION

Development and manufacture of large power transformers began in 1928, with the appearance of the first transformer for converting electrical energy from a 220 kV high-voltage network to a 110 kV medium-voltage network. It had a power rating of 60 MVA and a total weight of 182 t, excluding the independent cooling system which weighed 42 t.

The Loading-gauge profile dimensions determine the dimensions of the load (transformer), where the transformer height is determined by the height of the loading-gauge profile minus the height of the wagon. An optimal use of the transport profile is accomplished by employing the specialised two-part Schnabel wagons (Figure 1).

Figure 1: Specialised two-part goods wagon (Schnabel wagon) Model Uaai 821 (with 12 axles)

The first specialised wagons were developed in 1929. They had 18 axles; nine on each side. This ensured an even distribution of the loads on the axles of the wagon and on the tracks. The maximum carrying capacity of these wagons was 168 t.

When employing these specialised wagons, the transformer constituted a bridge between the two parts of the wagon. Via the tank-cage, a weight of the transformer was evenly distributed to the tapered, beak-shaped ends (Figure 2).

Figure 2: Connection between the transformer and the Schnabel wagon

In its role as the “bridge” in the Schnabel wagon arrangement, the transformer is connected to the specialised wagon via lower carrying lugs by means of pivots. At the same time, at the top of the carrier, the tank is wedged between the two Schnabel wagon sections by means of horizontal hydraulic buffers fitted to the top ends of the beams (Figure 2). When operating without a load, the two Schnabel wagon elements (and the rail composition itself) are linked into a single unit by means of lower pivots (Figure 1).

In the period between 1956 and 1965, the MAN Company manufactured and delivered six new 20-axle wagons with the maximum carrying capacities of 250 t

*Received 28 April 2015*
*Accepted 15 September 2015*

for various German electrical energy suppliers. The development of these Schnabel wagons continued in 1971 with the appearance of 24- and 32-axle wagons with carrying capacities of up to 457 t, where the weight of a 32-axle specialised wagon was 264 t.

Meanwhile, the “Deutsche Bahn (DB)” developed universal Schnabel wagons which allowed for a vertical and transversal adjustment of the placement of the lower pivots and the horizontal hydraulic buffers (Figure 2).

The process of mounting and starting-up a stationary power transformer requires a few days, whilst the time required for mounting and starting up a transformer manufactured for transport by the Schnabel wagons (with an inbuilt cooling system) is measured in hours. The obvious advantage of the transformers of this type is the possibility of moving them from one place to another in a short time, according to the network needs.

The paper employs principles of methodical construction with optimisation of the welded metal construction of a tank of a power transformer manufactured for transport by the Schnabel wagons with a maximum carrying capacity of 250 t.

Figure 3: Schnabel wagon with a cage-tank acting as a “bridge”

# 2 MAIN DESIGN

## 2.1 REGULATIONS AND NORMS

During transport by the Schnabel wagons, the load (transformer) – which constitutes an active connection between the two parts of the wagon – must comply with all regulations concerning construction, calculation, manufacture and quality assurance relating to the manufacture of railway vehicles (Figure 3). [3]

## 2.2 PROCESS OF TECHNICAL ELABORATION

The drafting of a fundamental construction solution is based on principles of methodical construction [6], and is divided into the following (basic) construction phases:

- planning and clearing of technical requirements (technical specification according to the buyer's requirements)
- conception (basic concept of a transformer with the dimensions of the active part)
- main design (optimisation of the active part and drafting main design)
- elaboration (preparation of the statics calculations and detailed technical documentation)

Based on the technical specification (provided by the buyer) the leading designer of the construction team makes a list of the equipment and parts necessary for transformer construction. In the elaboration phase, this list is supplemented and matched or adjusted according to the components available from the suppliers.

The processes of the conception and main design for this type of the power transformer require a broad spectrum of knowledge in the fields of electrical and mechanical engineering (statics, theory of hardness, fracture mechanics and methodical construction, with a special focus on the design of the welded metal constructions).

A partial overlap of the conception and elaboration phases introduces a dynamics into the process of construction and results in a reduction in the time necessary for preparation of the technical documentation.

## 2.3 MAIN DESIGN DEVELOPMENT

### 2.3.1 Active part

Based on the dimensions of the active part, the following basic components of the active part are modelled:

- core with the clamping system
- windings with leads
- main insulation

Windings with specific placement of the leads enable control of the necessary voltage clearance towards the parts of a different voltage level or phase.

When determining the terminal position and flux, it is necessary to take into account the possibility of local temperature rises in metal parts, due to the occurrence of a magnetic field around the conductor.

### 2.3.2 Loading gauge profile

The transformer dimensions are determined by the dimensions of the loading-gauge profile, where it is necessary to take into account the annotations given in the technical documentation for the specialised wagons [2].

The dimensions of a specialised wagon and the length of the transformer (distance between the lower carrying lugs) directly affect the useful width of the loading gauge profile (Figure 4).

A one-sided reduction in the loading gauge profile width (nominal width of the loading gauge profile is 3150 mm) for the specialised 20-axle wagon (Uaai 687.9) with the maximum allowed distance between the lower carrying lugs of 10 600 mm is 115 mm (for a length of 10 100 mm it is 107 mm, which makes the outer width of the tank ≤ 2 936 mm).

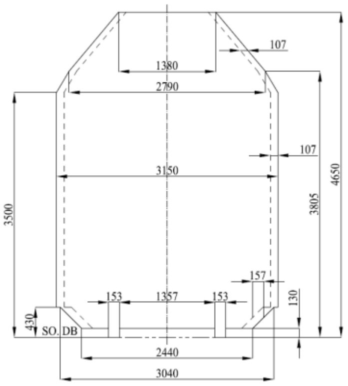

Figure 4. Dimensions of the loading gauge profile

### 2.3.3 *Steel parts*

All components of the transformer tank have to be placed in the space between the loading gauge profile, the terminals and the active part, where care must be taken to leave enough space for the horizontal and vertical stiffeners. The lower horizontal stiffeners with the lower carrying lugs and the upper horizontal stiffeners form a stable connection (bridge) between the front and the rear elements of the Schnabel wagon.

As a rule, this type of the transformer is constructed for transport by many different types of wagons. It is therefore necessary, during construction, to take into account technical differences between all chosen wagon types. The crucial factor in construction of the tank itself is the position of the upper and lower connection points with the Schnabel wagon. The dimensions of the carrier beams are limited by the internal dimensions of the tank and by the maximum width allowed by the profile. The dimensions are dependent both on the length of the transformer (see 2.3.2) and on the technological dimensions determined by statics calculations (in the statics calculations, the material utilisation is optimised according to the necessary welding thicknesses. [7]

In this case, the constructor must design (model) the welded parts so as to enable an optimal construction, which is only possible after a thorough, all-round examination of the process of manufacturing a welded construction.

In modelling a welded construction there are no prescribed, generalised techniques that can be applied to all construction assignments and which would allow a constructor to merely 'follow a recipe'.

This list of notes (recommendations) will enable a better overview of all factors that a constructor must take into account when designing and manufacturing a welded construction:

- construction with the smallest number of welds tends towards an 'optimal' solution
- choose the materials carefully
- use the materials maximally
- avoid welding the different materials together
- avoid accumulation of the welds (maximum two)
- appropriate choice of the type and form of the welds directly affects the distribution of forces in a welded construction (additional loads due to shortening of the material during welding and deformation of the welded construction) as well as the time necessary for construction
- shaping the welding elements depends on the type and form of the weld
- take account of the possibility of joining and accessing the welds (different widths of materials in butt-welds)
- prevent overheating of the edges of the welded construction

The wall of the tank between the upper and lower carrier beams needs to be reinforced, due to the occurrence of critical stresses in the following processes that the transformer is exposed to:

- vacuuming (drying and dehydrating the insulation)
- impact of the hydrostatic pressure of the oil during transport (if the transformer is transported with the oil)

In order to provide reinforcement between the upper and the lower carrier beams, vertical U-shaped stiffeners are used (made of bended sheet metal). The space between the stiffeners is used for mounting the control cubicles, cooling-equipment control cubicle and motor drive for the tap changer.

Other parts of the equipment are positioned according to the buyer's requirements, as described in the technical specification.

The horizontal stiffeners connect the longitudinal walls of the tank, where the upper and lower carrier beams are connected with the side-wall horizontal U-shaped stiffeners and as such form a cage around the tank. On the side walls of these specialised power transformers, cooling-system coolers are mounted, with ventilators integrated in the space between the upper and the lower carrier beam of the longitudinal transformer wall (Figure 2).

The space in front of the side wall, where the cooling system is placed, is divided into four independent compartments (by means of additional horizontal stiffeners), providing a separate space for each ventilator. The horizontal U-shaped side-wall stiffeners are connected with the vertical U-shaped stiffeners inside which the main cooling system pipes are placed. During transport, the bottom of the tank is under stress due to the weight of the active part, its own weight and the hydrostatic pressure of oil. The stresses on the bottom are distributed via the stiffened side walls of the bottom to the longitudinal lower and upper carrying beams. During the vacuuming process, the tank is placed on the wheel sets. The loads occur on the bottom of the tank due to the negative pressure, the weight of the active part and the bottom of the tank itself.

There are two different designs of the tank bottom. Where the bottom is constructed of a plate of a

30-50 mm thickness, it is referred to as a thick plate. Where the bottom is constructed of a bended plate which traces the shape of the loading gauge profile, of a 8-10 mm thickness, with the cross and longitudinal stiffeners, it is referred to as a skid base bottom. Its shortcomings are of a technological nature (bending, manipulation and welding of large plates) during manufacture. With the thick-plate bottom on the other hand, it is necessary to order an appropriate plate from the manufacturer timeously (price + weight ↑, number of welds + technological elaboration ↓, „Pareto optimum“↨).

The cover seals the tank on the upper side. The design in which it is connected with the active part (by a bolted joint) is used with the transformers of up to 100 MVA without the internal transversal stiffeners between the upper carrier beams.

In this case, the cover is an active part in the distribution of the loads in the tank (joint tank-cover) and it is included in the statics calculations. In the case of the cover not being connected with the active part (≥100 MVA), the tank is an independent carrying element, stiffened and stabilised by wrench-stressed internal stiffeners. Both types of the cover are subjected to stress during vacuuming and they need to be adequately stiffened by using corresponding stiffeners. A conservator is placed above the cover. The conservator shape follows the shape of the loading-gauge profile.

### *2.3.4 Main design*

After dimensioning the active part and determination of the necessary voltage clearance to the metal parts, the positions of the upper and lower tank-carrier beams, the dimensions of the cooling system, the positions of the transformer equipment and the geometry of all metal parts, a draft (model) of the transformer can be made (Figure 5).

## 3 STATICS CALCULATIONS

The metal construction has to be economical and fit for the purpose [9], [10], as well as possessing the necessary rigidity and stability (optimisation). The construction should be represented in the form of a model which will provide the best means by which to visualise the real situation that the metal construction will find itself in.

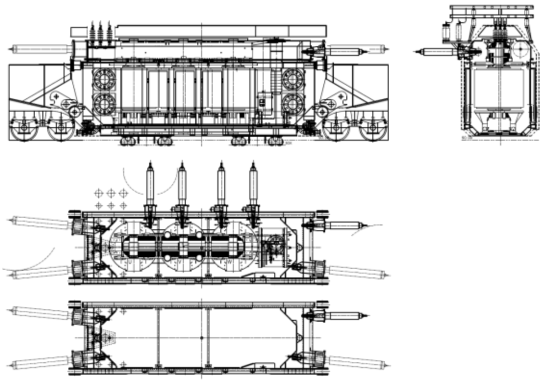

Figure 5: Main design of the Schnabel wagon transformer

Figure 6: Schnabel wagon transformer in the test field

The classical method for performing the statics calculations deals with calculating individual parts (segments) of the metal construction. In following this approach, significant simplifications of the real construction are made, where the calculations employ the basic elements of the statics (supports, carrier beams, grids, planes) or combinations of them.

All the necessary information (loads, moments of resistance and inertia, security factors, etc.) associated with checking the statics calculations for the metal construction has to be visible on the drawing or in the statics calculations themselves, along with the necessary annotations. The calculations should comprise equations, initial conditions, assumptions and applied methods.

The basic principles for making the statics calculations according to the classical method are detailed below.

### **3.1** *MECHANICAL STRESSES DURING TRANSPORT*

#### *3.1.1 Dimensions of a special wagon and position of the connection-point with the tank*

#### *3.1.2 Determination of the transformer centre line (in all directions)*

#### *3.1.3 Calculation of the safety factors for forces during transport for various positions of a wagon*

- horizontal
- when entering a bend (inclination)
- in the bend itself (inclination)

#### *3.1.4 Calculation of the forces in the upper and lower carrier beams for various states of a wagon in motion*

- starting-up
- hitting the buffers
- braking

#### *3.1.5 Determination of the forces in the carrying lugs of the lower carrier beam due to a non-*

*symmetric position of the transformer components (active part, cooling system, etc.) in the longitudinal/transversal direction*

*3.1.6 Determination of the position of the maximum moment (in all directions)*

*3.1.7 Calculation of the longitudinal sides with the upper and lower carrier beams connected by the vertical U-shaped stiffeners (calculation for transport with oil and for the process of vacuuming)*

3.1.7.1 Determination of the position of the neutral line of the longitudinal tank wall (shape and dimensions of the lower and upper carrier beams have a significant impact on the position of the neutral line) (Figure 7)

3.1.7.2 Determination of the moment of inertia of the longitudinal wall using the Steiner's rule [5] (C12, No.9)

$$Ja = Js + m \cdot a^2 \tag{1}$$

3.1.7.3 For the critical points on the longitudinal wall with the upper and lower carrier beam, it is necessary to determine the stresses for all wagon positions during transport with oil and during vacuuming [4] (page 58, Eq. 36)

$$\sigma_U = \sqrt{\sigma^2 + 3 \cdot \tau^2} \tag{2}$$

3.1.7.4 Determination of the shape and dimensions of the vertical U-shaped stiffeners between the upper and lower carrier beams (which also prevent deformation of the longitudinal walls during transport with oil or vacuuming)

- dimensions of the stiffeners (moment of resistance)
- position of the maximum force (during transport and vacuuming)
- loads, maximum moment in the stiffeners due to the hydrostatic pressure or during vacuuming

3.1.7.5 Determination of the positions and dimensions of the plates which prevent the occurrence of bulges during vacuuming or during transport with oil (if necessary) [4]

3.1.7.6 Positioning and dimensioning of additional stiffeners for the upper carrier beam horizontal hydraulic buffers

- surface area of the horizontal hydraulic-buffer pressure-piston activity
- position of the maximum forces (moments) for different positions during transport
- loads on the carrier beams and additional stiffeners

3.1.7.7 Stresses on the upper carrier beam as a result of the moments in the longitudinal walls incurred during transport with oil or the vacuuming without internal longitudinal stiffeners (the cover connected with the active part)

Action of the forces and moments in the nodes according to [1] (page 437, 114/1)

- determination of the moment on the upper carrier beam of the longitudinal wall by means of interpolation of a simple and bilaterally-wedged beam under a constant load [5] (C19, Table 4a, No.4; C21, Table 4b, No.8)

$$M = (-)\frac{F \cdot L}{16} \tag{3}$$

3.1.7.8 Stresses on the upper carrier beam as a result of the moments in the longitudinal walls incurred during transport with oil or vacuuming, with two internal longitudinal stiffeners (tank-cage)

Action of the forces and moments in the nodes according to [1] (page 438, 114/4)

- determination of the moment on the upper (statically indeterminate) carrier beam of the longitudinal wall using the Clapeyron's (three-moment) equation [8] (page 319, Figure 91)

$$M_0 \cdot l_0 + 2 \cdot M_1 \cdot (l_0 + l_1) + M_2 \cdot l_1 = -\frac{1}{4}\left(F_0 \cdot l_0^{\,3} + F_0 \cdot l_1^{\,3}\right) \tag{4}$$

$$M_1 \cdot l_1 + 2 \cdot M_2 \cdot (l_1 + l_2) + M_3 \cdot l_3 = -\frac{1}{4}\left(F_0 \cdot l_1^{\,3} + F_0 \cdot l_2^{\,3}\right) \tag{5}$$

*F0 is the impact of oil (vacuum) on the longitudinal tank wall, l0 is the distance from the start of the longitudinal wall to the first transversal rod stiffener, l1 is the distance from the first to the second transversal rod stiffener, l2 is the distance from the second transversal rod stiffener to the end of the longitudinal tank wall.*

- determination of the forces and loads on the internal stiffeners
- determination of the safety factors for the wrench stress on the internal stiffeners (rods) [4]

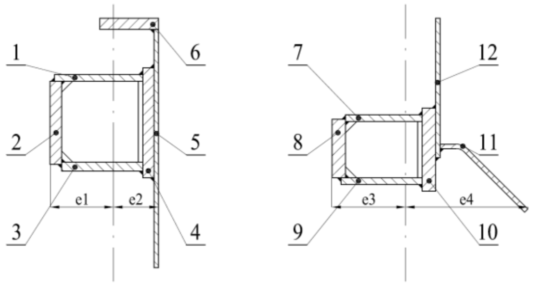

Figure 7: Cross-section of the upper and lower carrier beams

3.1.7.9 Positioning and dimensioning of the lower carrier beam

- position of the maximum forces (moments) for different positions during transport

- loads on the carrier beam and on additional stiffeners

#### 3.1.7.10 Lower carrier-beam lugs

- dimensions of the lugs and critical cross-sections in all directions (moment of resistance)
- forces in different directions (three-dimensional)
- stresses in the material (2)

#### 3.1.7.11 Characteristics of the lug welds on the upper and lower carrier beams [2]

- dimensions of welds (surface area, position of centres of gravity of all welds, moment of inertia)
- moments in the welds (three-dimensional)
- stresses in the welds [4] (page 82, Equation 72)

$$\sigma_h = \sqrt{\sigma_\perp^2 + \tau_\perp^2 + \tau_{\mathrm{II}}^2} \tag{6}$$

### 3.1.8 *Calculation of the side walls with the horizontal stiffeners between the upper and lower carrier beams (the upper and lower frame are connected with a U-shaped stiffener into which the cooling system pipeline is integrated)*

#### 3.1.8.1 Determination of the shape and dimensions of the horizontal bracings and their positions on the side walls (position follows the longitudinal walls' upper and lower carrier beams)

- upper transversal U-shaped stiffener which connects the longitudinal side upper carrier beams
- middle transversal T- or U-shaped stiffener which divides the side wall (horizontal and vertical stiffeners divide the space in front of the side wall into four separate parts into which the cooling-system ventilators are independently placed)
- lower transversal U-shaped bracing which connects the longitudinal side lower carrier beams

#### 3.1.8.2 Forces that act on individual horizontal stiffeners

- during transport with oil

$$F_0 \Rightarrow F_T = \rho_{Öl} \cdot B \cdot L \tag{7}$$

- during vacuuming

$$F_0 \Rightarrow F_{0,1} = 0{,}1 \cdot B \tag{8}$$

Where $\rho_{Öl}$ is the hydrostatic pressure, $B$ is the height of the surface on which the hydrostatic pressure (vacuum) acts, $L$ is the length of the surface on which the hydrostatic pressure (vacuum) acts.

- moments due to the forces on the side walls (according to expression (4))
- determination of the reactions in the carrier beams

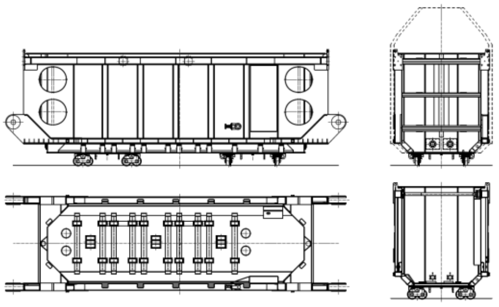

Figure 8: Tank drawing (statics calculations)

### 3.1.9 *Calculations for the tank bottom (during transport with oil and during vacuuming)*

During transport with oil, the tank bottom is under stress from the hydrostatic pressure of oil, from the weight of the active part, and from the vertical components of the bottom and the tank. During vacuuming, the bottom is under stress from the weight of the active part, from stresses due to vacuum on the side and longitudinal walls and from the reactions in the wheel sets.

The necessary stability and bearing capacity of the tank bottom are achieved in two ways: by constructing the tank bottom from a thick plate with internal stiffeners (thick bottom) or by employing a thin bended bottom with external stiffeners of different shapes, depending on the place of the action of forces of individual transformer components (Figure 9).

For a series of technological reasons (dimensions of the brake press, butt-welding of large surfaces and overlapping with longitudinal and transversal stiffeners on the bottom, time of manufacture, difficulty in checking the welds, anticorrosive protection, quality) it has largely become the rule to employ the thick bottom tank design with the internal stiffeners in the space between the lower edge of the active-part core and the bottom of the tank.

#### 3.1.9.1 Determination of the bottom thickness, position and dimensions of the internal stiffeners

#### 3.1.9.2 Determination of the moment of inertia for different forms of the tank bottom stiffeners

#### 3.1.9.3 Forces on the tank bottom during transport

- vertical components
- horizontal components (due to the shape of the tank bottom determined by the loading gauge profile)
- components of the resultant force

#### 3.1.9.4 Forces on the tank bottom due to vacuum (walls, tank bottom and cover 0.1 N/mm2)

- vertical forces of the components (vacuum, active part, wheel sets) according to 3.1.7.8

$$T_0 = \frac{q_0 \cdot l_0}{2} + \frac{M_1}{l_0} \tag{9}$$

$$T_1 = \frac{q_0 \cdot l_0 + q_1 \cdot l_1}{2} + \frac{M_2}{l_1} - M_1 \cdot (\frac{1}{l_0} + \frac{1}{l_1}) \tag{10}$$

$$T_2 = \frac{q_1 \cdot l_1 + q_2 \cdot l_2}{2} + \frac{M_1}{l_1} - M_2 \cdot (\frac{1}{l_1} + \frac{1}{l_2}) \tag{11}$$

$$T_3 = \frac{q_2 \cdot l_2}{2} + \frac{M_2}{l_2} \tag{12}$$

- horizontal forces arising in the longitudinal walls which affect the tank bottom

*Initial condition: the transformer is a homogeneous three-dimensional body, and the active part represents a homogeneous elastic body of a constant cross-section.*

3.1.9.5 Maximum moment during transport is determined by the three-moment equation

3.1.9.6 During vacuum there are different values of the moment depending on the forces on the characteristic cross-sections.

- Characteristic cross-section A-A (vacuum, active part and wheel set)
- Characteristic cross-section B-B (vacuum and wheel set)
- Characteristic cross-section C-C (vacuum and active part)
- Characteristic cross-section D-D (vacuum)

*Explanation:*

*The transformer can be cut transversely along its length into infinitely many parts. It has been observed that there are a few characteristic cross-sections on which different forces appear.*

3.1.9.7 Determination of the maximum stresses in a thick tank bottom with the stiffeners for all characteristic cross-sections and shapes

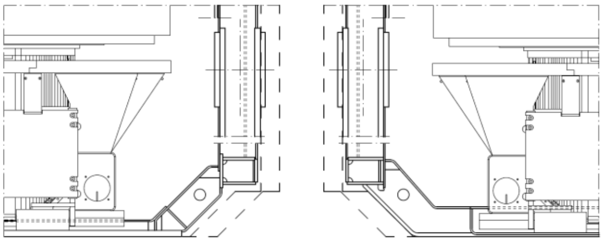

Figure 9: Details of the tank bottom design

[Thick bottom (left) and skid-base bottom (right)]

### *3.1.10 Connection between the tank bottom and longitudinal sides (loading-gauge profile shape)*

For the maximum horizontal and vertical forces in the lower carrier beams it is necessary to dimension the welds for the shear stress during transport or vacuuming (see 3.1.9.6).

### *3.1.11 Stresses in the wheel sets*

When the transformer is placed in its location, wheel sets are loaded with the weights of the tank with the cover, the active part and oil.

- forces in the wheel sets are determined by applying the three-moment equations for the statically indeterminate carrier beam with six supports in the longitudinal direction of the transformer (see equations at 3.1.9.4)
- forces in the wheel sets are distributed in the transversal direction of the transformer (we use the factors of distribution obtained from the geometric similarity of the position of the wheel sets in relation to the dimensions of the tank bottom)

## *3.2 CALCULATION SYNTHESIS*

The statics calculations are a basic prerequisite for making the final technical documentation for the tank. They are carried out as an iterative process with the aim of achieving an optimal construction solution according to the relevant, applicable regulations. [3][4][7]

The statics calculations made in this way (by the classical method, with the elements of the optimal construction) are a basis for modelling and analysing the tank construction using 3D models (Figure 10) and the finite-elements method (FEM).

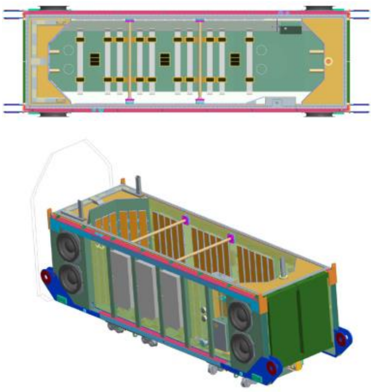

Figure 10: Model of the tank in ProE

## 4 CONCLUSION

Development of a welded metal construction for the “bridge” transformers (tank-cage) requires the knowledge of many branches of electrical and mechanical engineering, with a special focus on the techniques of the methodical construction of the welded metal constructions, statics, theory of hardness and fracture mechanics, as well as the knowledge of regulations imposed on the railway vehicle manufacture.

When making the statics calculations together with technical documentation, it is necessary to study the relations and connections between all parts of the welded metal construction, so as to ensure that the final solution satisfies all the applicable, regulations and norms.

Carrying out the statics calculations for the metal construction according to the classical method is a long and demanding process, which it is now possible to entrust to computers.

New calculation methods involving computers have enabled solving the statics problems that had previously highly complex (if not impossible) to solve using the classical method (in the sense of formulating, solving and calculating a mathematical model).

The problems falling into this category include all those relating to the metal constructions as well as those concerning the welded metal construction of the "bridge" transformer.

The engineer's required knowledge has not been simplified or made superfluous by using computers, as is often suggested in descriptions of commercial programs, but has rather taken on a new dimension. The body of the required knowledge has broadened beyond the theoretical and classical approaches to solving the statics problems, in creating an adequate model which will completely satisfy the expectations and assumptions of the constructor.

The advantages gained from such a three-dimensional complex approach enable discovery and utilisation of all possible reserves which could not have been recognised by the classical method, and by extension could not have been applied in looking for an optimum. It should be emphasised that during evaluation of the statics calculations it is necessary to independently assess the mathematical model (which is a simplified version of a realistic model) as well as the program (software) for calculation.

The developments in the software and calculation methods are today almost limitless, since new programs and methods are worked on every day. Hence, a thorough knowledge of the complete range of the technical basics, and statics in particular, is essential in the everyday work of not only the scientific researchers but also engineers involved with the welded-metal constructions.

The statics calculations performed using the classical method provide an overview and an insight into problematic aspects of the bridge-transformer construction, and as such represent a basis for developing an adequate mathematical model and choosing an appropriate software for calculation and optimization.

## FIGURE (SOURCE)

### SGB-SMIT Regensburg, Germany

| | |
|---|---|
| Figure 1: | Specialised two-part goods wagon (Schnabel wagon) Model Uaai 821 (with 12 axles) |
| Figure 2: | Connection between the transformer and the Schnabel wagon |
| Figure 3: | Schnabel wagon with a cage-tank acting as a "bridge" |

### SIEMENS AG, Dresden, Germany

| | |
|---|---|
| Figure 4: | Dimensions of the loading-gauge profile |
| Figure 5: | Main design of the Schnabel wagon transformer |
| Figure 6: | Schnabel wagon transformer in the test field |
| Figure 7: | Cross-section of the upper and lower carrier beams |
| Figure 8: | Tank drawing (statics calculations) |
| Figure 9: | Details of tank-bottom design [thick bottom (left) and skid base bottom (right)] |
| Figure 10: | Model of the tank in ProE |

## BIBLIOGRAPHY

[1] Kleinlogel, A.: Rahmenformeln. Verlag Wilhelm Ernst & Sohn, Berlin 1957

[2] DB DS 934 Verzeichnis der Tiefladewagen. Deutsche Bundesbahn (01.01.1993)

[3] DIN EN 15085-1,-2,-3,-4,-5 Januar 2008 (DIN 6700-1,-2,-3,-4,-5 (≤ 31.12.2010))

[4] DIN 18800-1,-2,-3 Novembar 2008

[5] Dubbel - Taschenbuch für den Maschinenbau. 23.Auflage, Springer-Verlag 2011

[6] Pahl, G.; Beitz, W.: Konstruktionslehre-Grundlagen erfolgreicher Produktentwicklung-Methoden und Anwendungen. 5.Auflage, Springer Verlag 2003

[7] Büttemeier, H.; Kaßner, M.; Strothmann, M.: Schweißtechnisches Handbuch Schienenfahrzeugbau. Verlag DVS 2010

[8] Netz, H.: Formeln der Technik. 2.Ausg. Verlag Carl Hanser, München Wien 1983

[9] Fischer, J.O.: Kostenbewustes Konstruieren. 1.Aufl. Berlin Heidelberg: Springer-Verlag 2008

[10] Ehrlenspiel, K.; Kiewert, A.; Lindemann, U.: Kostengünstig Entwickeln und Konstruieren. 6.Auflage Berlin Heidelberg: Springer Verlag 2008.

**Roman Žičkar** earned a degree in Mechanical Engineering from the University of Zagreb in 1994. The same year he started working as a Mechanical Designer for Končar Power Transformers in Zagreb, becoming their Lead Designer in 1998 and later moving to the same post at SGB-SMIT in Regensburg. In 2005 he joined the Siemens transformer factory in Dresden; having been a Senior Key Expert and a Principal Key Expert, he is now the Head of Mechanical Design. In addition to his research-oriented master's degree completed in 2011 at the University of Zagreb, in 2013 he decided to pursue a Ph.D. at the Chemnitz University, Germany. He actively participated in a number of international symposiums.