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INFLUENCE OF BARREL DAMAGES ON LIFE TIME OF TANK WAGON

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Abstract: *Analysis of damages of such elements of barrel where fatigued cracks appear during the barrel exploitation time was performed. Normative calculations which confirmed sufficient strength of the barrel were implemented. To substantiate heightened level of stresses in local areas of the barrel the additional calculations were performed in accordance with elaborated modes of loading. During CAE simulation the risky levels of stresses in mentioned areas without damages, with damages and repaired damages were obtained as a result of simulation. Recommendations for preparing and counting of results of calculating models in areas of damages and concentrators of stresses are given. The changes in resource of barrel of tank car, depending on the type of damage and variants of damage repair, were defined.*
Key words: Railway tank wagon, barrel damages, SW Simulation, stress-strain analysis, life time.

1. INTRODUCTION

From all variety of railway tank wagons let consider the tank wagons which are used for transportation of liquid and highly dangerous goods. To strength of barrels of tank wagons increased demands are being made towards their strength on stages of designing, testing and technical examination. The barrels which being put into operation have strength reserves necessary in accordance with the "Norms …" [1] during service term which being set by manufacturer. However during operation before the service term end the fatigued cracks of the barrel elements appear. In conditions of Latvian railway the main damages of the barrels of oil tank wagons and their quantity (Fig. 1.) are: cracks of welding seams of shaped pads – 50%, barrel damages in area of supports – 30%, damages of welding seams of the barrel – 15%, unfastening of shaped pads – 5%.
Distribution of damages tallies with statistical data of tank wagons for transporting of liquefied hydrocarbon gases (LHCG) which given in the work [2]. Considerable damaging of welding seams of the barrel is due to higher level of pressure in the barrel in comparison with oil tank wagons (Fig. 2).

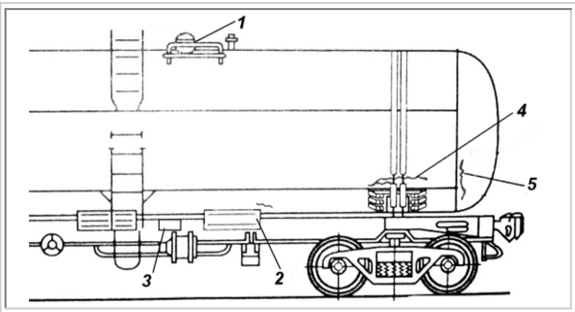

Fig. 1. Areas of damages of barrel of tank wagon: 1-welding seams of manhole hatch, 2-welding seams of shaped pads, 3-welding seams of discharging device, 4-welding seams of the barrel shell near supports, 5-welding seams of dome

As causes of such quantity of damages, possible, are the following: constructive concentration of stresses and concentration of stresses in welding seams, defects of welding seams, uneven wear of the structure elements, high longitudinal forces

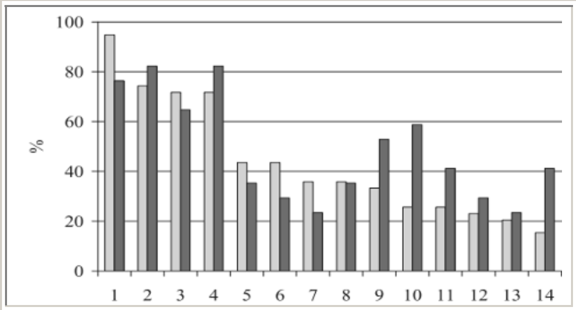

Fig. 2. Statistical data about damaging of tank wagons 903P and 15-1407 accordingly: 1-cracks of welding seams of shaped pads, 5-damage of support, 10-defects of the barrel welding seams, 13-unfastening of shaped pads, 14-unfastening of retaining bands. The rest points don't shown as they concern the wagon frame

during shunting works with heightened speeds and emergency situations (emergency braking, collisions between wagons and with obstacles), longitudinal forces of hydraulic stroke of the cargo.
To define causes of the barrel damages before end of set service term it is necessary to evaluate values and character of the acting loads.

2. LOADS AND MODES WHICH LEAD TO DAMAGES

2.1. Normative calculation

To evaluate influence of loads to stressed state of areas where damages occur, calculation of strength of barrel of loaded tank wagon of model 15-Ц863 done for modes of loading which prescribed in the "Norms …" [1]: 1st (extraordinary mode), 3rd (operation mode), testing pressure, vacuum acting per pressure of the safety valve in the empty barrel. To estimate contribution of horizontal and vertical forces into the barrel stressed state additionally calculations of strength under acting of vertical dynamic forces and horizontal forces of hydraulic stroke were carried out.
The barrel is made from steel Вст3 (yield strength σ_T=245 MPa, breaking point σ_B=390 MPa [1]). In result of analysis of the stressed state the loads which cause the highest stresses were defined: in the areas 1, 3 – load from testing pressure and load of the 1st mode, in the area 2 – loads of the 1st mode and from hydraulic stroke of the cargo, in the area 4 – loads of the 1st mode, in the area 5 – loads of the 1st mode and load from testing pressure. The loads enumerated in order of their significance. Values of amplitudes of dynamic stresses in whole range of loads from empty condition till extraordinary loads were defined (Fig. 3).

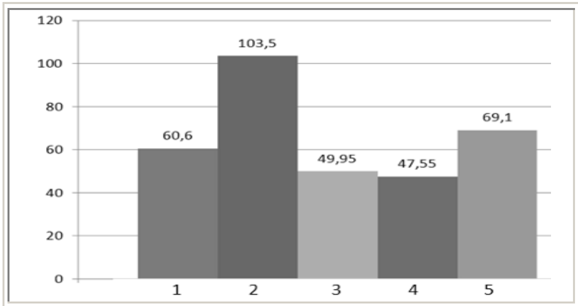

Fig. 3. Amplitudes of equivalent stresses of barrel of wagon 15-Ц863 in areas No. 1-5 (Fig. 1)

Higher amplitudes arise in the barrel shell – area of shaped pads 2 and in welding seams of the barrel dome – area 5. Amplitudes for the area 4 are minimal, but during operation in 30% of cases there arise cracks and deformations.
As per the normative calculations the barrel strength is in accordance with condition of sufficient strength (Table 1.).

No. of area, name	Stress, MPa	
	Modes	
	1st	3rd
2 Pads	208	99
5 Dome	146	89
4 Supports	101	60

Table 1. Maximum stresses under first and third modes of loading

Arising of damages in operation, possible, is caused by such fact that the normative calculations don't take into account character and values of the barrel loads in full, or don't take into account character of the loads damaging effect in one or another area of the barrel. Therefore models for evaluation of the stressed state in local areas No. 2, 4, 5 (Fig. 1) where the barrel damages arise were developed. Simulation of damages (defects) of the barrel for these areas was implemented.

2.2. CAE simulation

For creation of model of the barrel and models of damages the AutoCad program was used. The strength calculations were made using FEM programme SolidWorks Simulation. Since the design and loads acting are symmetrical calculations of the barrel damages were made on ¼ part of the model (Fig. 4.). To cutting edges of the model border boundary conditions Symmetry were put.

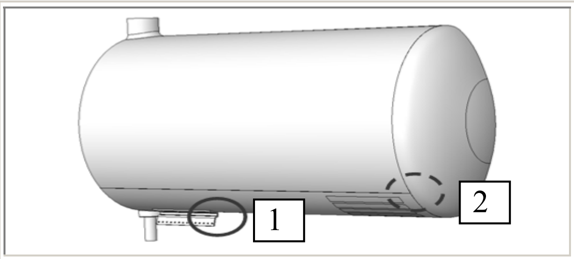

Fig. 4. Calculating model ¼ of barrel: 1-welding seams of shaped pads, 2-T-joint of the barrel seams

Due to curved surface of the structure the finite elements of the second kind (Mesh quality-High) were used, mesher type – Standard – this mesher is faster, Automatic transition – On. Small surfaces of cracks and concentrators of stresses in the area being analysed are divided by smaller mesh by hand, using Mesh Control, finite element size is 6 mm in zone 1 (Fig.4.) and in zone 3 (Fig.1.). The defect dimensions should be larger than the mesh value of inaccuracy in this area for one-layer dividing. In areas of cracks and in transitional areas equal dimensions of the mesh for inner and outer walls of the barrel (element) were set, that furthers formation of finite elements with regular shape. Number of elements in FE model is about 464052. After developing of model quality of the mesh being verified numerically (Mesh properties) per quantity of elements with irregular shape and visually.
Strength of the barrel is evaluated per equivalent stresses. Results are counted at distance 20-25 mm from concentrators of stresses using strain gauges with base 10-20 mm for environmental tests of wagons. Dimension of finite elements in these areas should correspond with dimensions of the strain gauges.

2.3. Simulation of damages of the area of shaped pads (pads)

As per results of the normative calculation without damages of the barrel strength in area of pads is sufficient. During operation cracks arise in this area: 1 – in transversal welding seam of the pads, 2 – in the barrel shell (Fig. 5). Simulation of more frequent damage No. 1 was implemented.
The created detailed model of pad is welded to the barrel shell not by whole contact area (as it is taken in the normative calculation), but by perimeter, longitudinal and transversal welding seams and seams in cuts of the pad middle part (Fig. 5.). Variants calculations of the pad strength for transversal seam in manufacturer's, repairs' performances and with crack on whole width of the pad (Figures 6, 8, 10.) were executed.

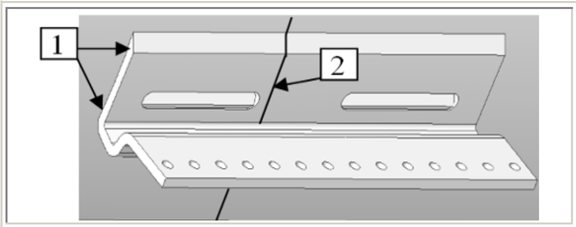

Fig. 5. Model of pad. Scheme of pads' cracks: 1-in transversal seam, 2-in the barrel shell

From results of the calculations defined that in case of manufacturer's performance of the transversal welding seam (Fig. 6, length about 100 mm) stresses reach

65MPa, and 96MPa in joint with the longitudinal seam (Fig. 7).

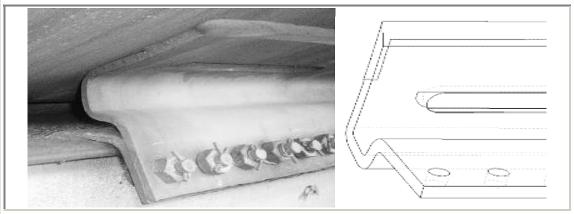

Fig. 6. Manufacturer's performance of transversal seam of the pad on wagon and in the model

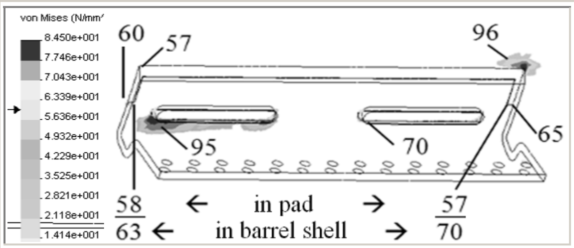

Fig. 7. Stresses of the pad, MPa (seams in manufacturer's performance)

When the transversal seam in repairs' performance has length equal to width of the pad (Fig. 8), stresses in the welding seam grow by 2.1 times and reach 145 MPa, and 93 MPa in joint with the longitudinal seam (Fig. 9). In end of welding seam (concentrator of stresses), when the seam length is maximal, stresses reach 240-400 MPa, that exceeds yield strength and limit strength of the material, and corroborate arising of cracks.

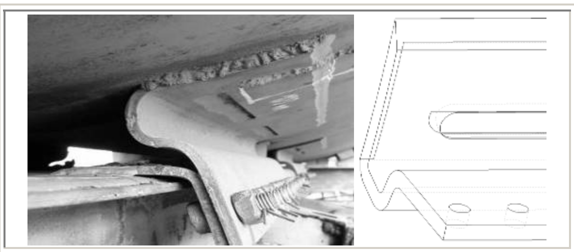

Fig. 8. Repaired transversal seam of the pad on wagon and in the model

In case of crack in transversal seam (Fig. 10), stresses in ends of longitudinal seam reach 57MPa and 95MPa (Fig. 11).
Stresses in welding seams in cuts of middle part of the pads reach 77MPa and 101MPa. Crack in transversal seam not lead to growing of stresses in longitudinal seam,

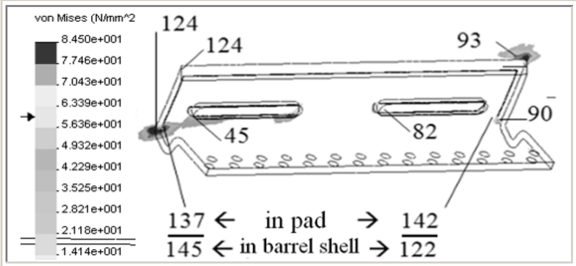

Fig. 9. Stresses of the pad, MPa (length of seams – as far as the pad width)

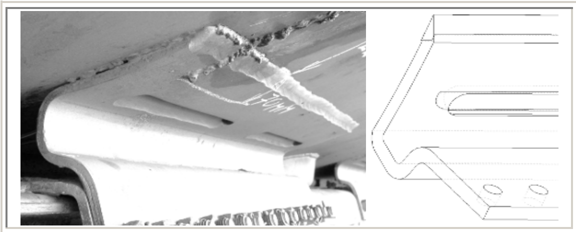

Fig. 10. Crack in transversal seam of the pad on wagon and in the model

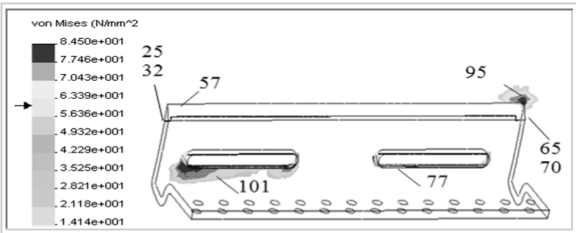

Fig. 11. Stresses of the pad, MPa (seams with cracks)

but in welding seams in cuts of the pads stresses have grew by 9% in comparison with stresses in case of manufacturer's performance of the transversal seam.
During repair it is necessary to control length of transversal seam which should be in limits from 100 mm till ~140 mm (till line of projection of longitudinal seams in cuts of middle part of the pad to line of the transversal seam).

2.4. Simulation of damages of the area of supports

In accordance with results of the normative calculation (Table 1) the barrel strength in area of pads is sufficient. During operation cracks arise in this area: in horizontal welding seam of the barrel shell near supports (area 4 – Fig. 1), in vertical seam of dome near supports (area 5 – Fig. 1).

Uneven sagging and wear of the supports, which made from wood, lead to the barrel leaning on the upper supports. Results of simulation of such case are shown on Fig. 12, and in Table 2.

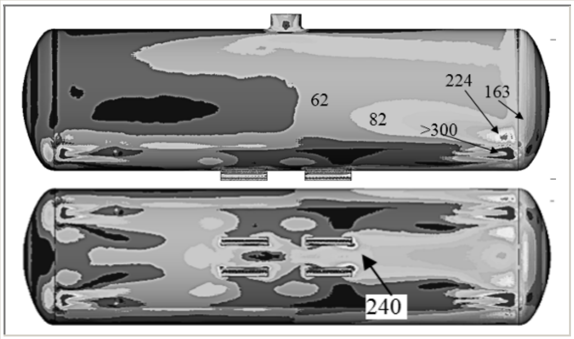

Fig. 12. Equivalent stresses when the barrel leans on upper supports

Stresses in area of the barrel shell are higher than yield strength of the material, which leads to arising of the barrel shell deformations and welding seams' cracks in areas No. 4, No. 5 (Fig. 1) during operation.

No. of area, name	Stress, MPa; 1st / 3rd mode		
	By Norms	Sagging of supports	Increase
2 Pads	208 \ 99	240 \ 110	32 \ 11
5 Dome	146 \ 89	163 \ 103	17 \ 14
4 Supports	101 \ 60	224 \ 130	123 \ 70

Table 2. Evaluation of the central supports sagging influence to the barrel stressed state

During repair it is necessary to control if the supports fit closely to the barrel shell. For calculations of the barrel it is necessary to take into account uneven leaning on supports.

3. ESTIMATION OF THE BARREL LIFETIME

Let implement calculating estimate of remaining lifetime for the barrel per two criteria [3]: 1 – per destruction from single blow (extraordinary loads); 2 – per accumulation of residual deformations.

3.1. Estimation of lifetime till single fracturing blow

Mathematical expectation of quantity of blows $\bar{n}$ till arising of bearing elements damages being defined by approximate relation:

$$\bar{n} \approx 1/p, \qquad (1)$$

where p – probability of such blow, in the time of which stresses in some bearing element will exceed the breaking point.

When the longitudinal forces distribution function P is known, then this probability

$$p = 1 - P_i, \qquad (2)$$

where P_i – value of distribution function for such values of forces when the acting stresses not more than permissible level.

As quantity of longitudinal blows per year is known it is possible to evaluate lifetime approximately per this criterion.

As per the normative calculations, the highest stresses in the barrels are in seams of welding of pads to the barrel shell (area 2, Fig. 1) – 208 MPa from longitudinal load 2.5 MN. Parameter of Rayleigh distribution for this point is: S=(208×0.88)/2.5 =73.21 MPa.

Breaking point of heavy-plate steel ВСт3 is 390 MPa and includes 5.327 scale parameters. Probability of this level exceeding is p=1–0.999999, and mathematical expectation of quantity of blows till damaging level will reach 1000000, and as the quantity of compression blows per year is 7500, it corresponds to 193 years of operation.

In calculation for additional modes – in case of enlarged length of transversal seam of pads and in case of the barrel leaning on the upper supports mode, – stresses in pads will grow up to 240 MPa. In such case lifetime will sink till 5.66 years, and it confirms possibility of non-permissible cracks (damages) arising in pads of 30% wagons in operation between major repairs of the wagons (8 years).

3.2. Estimation of lifetime per low-cyclic fatigue

Average time till accumulation of plastic yield when crack in a bearing element arises can be defined from the formula below:

$$\overline{T} = \frac{\sigma_{-1}^{m} N_0}{n_g 2^{\frac{m}{2}} \Gamma\left(\frac{m}{2}+1\right) S^{m}}, \quad (3)$$

where G_{-1} – fatigue endurance limit on base $N_0=10^6$ cycles (taken per the fatigue curve on base 80000 cycles as 140 MPa); m – slope of the S-N-curve (for the carbon steel m=3.33); n_g – quantity of compression loads during one year of operation; $\Gamma(...)$ – gamma-function.

As per the normative calculation the higher stresses in area of seams of the pads are 208 MPa. Lifetime per criterion of low-cyclic fatigue will be 19 years. In mode of the barrel leaning on the upper supports and in case of enlarged length of transversal seam of pads the lifetime in area of the pads is T_{240} = 12 years. In the barrel shell in area of supports T_{224} = 15years. The calculation estimation of the remaining lifetime confirms possibility of fatigue cracks arising between major repairs of wagons in areas of pads and supports (Table 3.).

No. of area, name	Lifetime per low-cyclic fatigue, years		
	By Norms	Sagging of supports	Decrease
2 Pads	19	12	7
5 Dome	63	43	20
4 Supports	214	15	199

Table 3. Evaluation of the central supports sagging influence to the barrel remaining lifetime

4. CONCLUSION

From statistical data and calculations follows, that there are two areas which are subject to larger damages: cracks of welding seams of shaped pads and cracks of barrel in area of supports. Main loads and elements of the barrel which limit lifetime of tank wagon were defined on base of results of normative calculations and new-worked out modes of loading. Measures for lifetime increasing are elaborated and proposed. Recommendations for preparing of simulation of damages with small dimensions by means of CAE are given.

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