Influence of Wheelset Tortuous Motion on the Stress-Strain State and Contact Pressure at the Labyrinth Ring-Axle Interface

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**Abstract.** This paper presents the results of a study based on a developed finite element model of the press-fit connection between the labyrinth ring of the axle unit and the seating surface of the wheelset, considering the impact of wheelset tortuous motion on the railway track. The influence of this motion on the stress-strain state and contact pressure within the press joint is evaluated.

**Keywords:** Finite element model, press-fit connection, labyrinth ring, axle unit, wheelset, tortuous motion, railway track, stress-strain state, contact pressure, press joint

# INTRODUCTION

The safety of train traffic is largely determined by the reliability of wheel sets, which, in turn, depends on the strength of press connections of their elements (in general for all types and kinds of wagons: thermal pressing of inner rings of axlebox bearings, thermal pressing of labyrinth rings of axlebox units and longitudinal pressing of solid rolled wheels on the corresponding sections of the axle of the wheel set). Of all the listed types of press connections of wheel set elements, thermal pressing of labyrinth rings of axlebox units is the least studied. In the first half of 2024 the number of uncouplings in the current uncoupling repair of freight wagons of the freight fleet of the Russian Federation for the axlebox unit was 1.8% (12,200 uncouplings) of this number for reasons of faults (operational, technological, damage) for axlebox units out of 100% of technological faults the axlebox unit occupies – 5%, and for damage – 1.8% [1, 9, 11, 13].

Thus, it can be said that the study of the strength of the connection between the labyrinth ring of the axlebox unit and the grazing surface of the corresponding part of the wheelset axle is an important scientific and practical task, the solution of which will improve the safety of train traffic and reduce operating costs associated with the need for unscheduled repairs [6, 8, 10].

Pressed joints in the process of operation are exposed to operational factors of various nature, one of which is tortuous movement on the railway track.

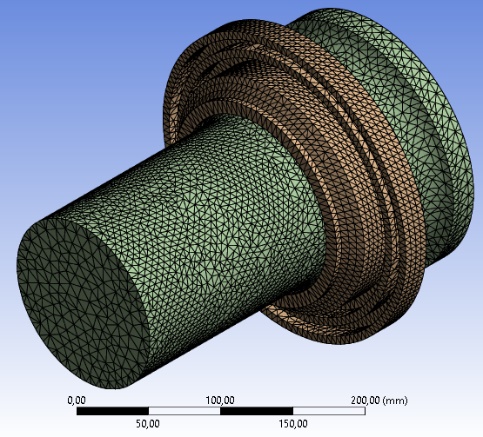
The first stage of the research is theoretical and includes the creation of a computer model of the press joint and its finite element analysis.

# CREATION OF A FINITE ELEMENT MODEL OF THE CONNECTION

To carry out the research, a model of the connection between the labyrinth ring and a part of the wheelset axle was created [2].

The coupling model is based on the elastic formulation of the problem and consists of a part of the wheelset axle as well as the labyrinth ring.

The finite element model, shown in Figure 1, consists of 50392 finite elements and 89392 nodes.



**FIGURE 1.** Partitioning of the finite element model of the press connection of the labyrinth ring with the axle (part of the axle) of the wheelset

The obtained model of the press connection takes into account the following parameters: taper and ovality of the seating surface of the axle of the wheel set, taper and ovality of the seating surface of the labyrinth ring, tension and angle of defects in the geometry of seating surfaces relative to each other.

The range of interference variation according to [3] is from 0.020 mm to 0.186 mm. The ovality of the cylindrical surface of the axial part was modelled to be equal to the maximum permissible 0.05 mm [4], as was the ovality of 0.1 mm and taper of 0.05 mm for the seating diameter of the labyrinth ring [3].

The stresses were recorded in four sections on the outer surface of the labyrinth ring, and the average value of equivalent stresses for each section was calculated according to the following relationship:

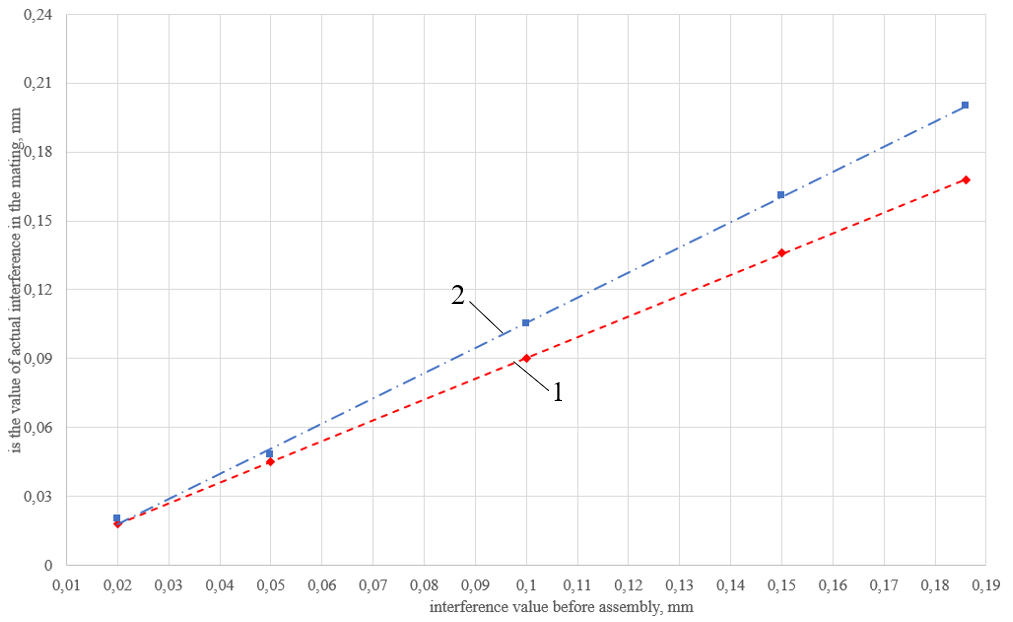
*σequiv* =  (1)

where *n* is the number of points in each section n = 112.

Current regulatory documents do not regulate the location of deviations from the correct cylindrical shape of the contact surfaces of the labyrinth ring and the seating surface of the axle of the wheelset relative to each other, and in practice a large variation is possible, so to obtain the dependence of the actual tension on the measured one in operation it is advisable to use the average dependence on the data obtained during the study of the finite element model at different angles, shown in Figure 2.

Under normal operating conditions, no load is applied to the labyrinth ring, as its task together with the labyrinth seal in the axlebox housing is to isolate the internal volume from the environment. Otherwise, when the load is applied directly to the labyrinth ring, the likelihood of failure of the labyrinth seal increases [7, 9, 14].

To verify this assumption, a load from 1.5 to 16 tonnes with a step of 1.5 tonnes with tension values of 0.02 and 0.186 mm was applied to the axle neck of the wheelset axle of the developed model. As the analysis of the results shows, the change in the stress-strain state from loading the wagon does not exceed 0.00652 MPa, which leads to a change in the value of the tension by about 0.0001 mm. This allows us to say that loading in pure form, without taking into account other influences, practically does not cause a change in the strength of the press connection under consideration.

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**FIGURE 2:** Dependences between the actual interference fit and the measured preassembly interference fit according to the diameter difference: 1 – with ideal seating surfaces y = 0,9053x-0,0002; 2 – with tapered and oval seating surfaces according to [4]  
y = 1,0969x-0,0042 (R2=0,9994)

Due to the presence of structural cones on the rolling surface for independent installation of the wheelset in the track on a straight section of track, in addition to the vertical load on the axle neck, an additional force will alternately act on its end, determined by the existing method [5, 17, 19], according to the dependence:

(2)

where – gross weight of the wagon; – number of wagon axles; – acceleration of free fall, 9.81 m/s2;   
 – coefficient of horizontal dynamics.

The coefficient of horizontal dynamics is determined according to [5, 18, 20]:

(3)

where – is the speed of the wagon, m/s; = 1,0 (for 4-axle freight, isothermal and passenger wagons); = 1,0∙10-3 (for freight wagons); = 40 (for all wagons); = 3,9 (for freight wagons).

The frame force for the load range of 1.5 tonnes and 16.5 tonnes per axle neck, at speeds from 25 to 200 km/h are given in Table 1.

**TABLE 1.** Frame force for 1.5 and 16.5 tonnes load when the tortuous motion of the wheel set

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **Н (at a load of 1.5 tonnes), kN** | **Н (at a load of 1.5 tonnes), kN** |
| 25 | 0,1375 | 4,046625 | 44,5129 |
| 50 | 0,235 | 6,91605 | 76,0766 |
| 75 | 0,3325 | 9,785475 | 107,6402 |
| 100 | 0,43 | 12,6549 | 139,2039 |
| 125 | 0,5275 | 15,52433 | 170,7676 |
| 150 | 0,625 | 18,39375 | 202,3313 |
| 175 | 0,7225 | 21,26318 | 233,8949 |
| 200 | 0,82 | 24,1326 | 265,4586 |

In [6, 15, 16], the following formulas are used to determine the tortuous motion parameters of a typical wheelset:   
- frequency of tortuous motion of the wheelset (λ)

(4)

where – speed of movement, m/s; – slopes of rolling surfaces of wheels, for typical values ;   
 – radius of solid rolled wheel, 0,475 м; – distance between meridional points of contact of wheels with rails,  
 1,58 м.

- period of tortuous motion (*T*):

(5)

- is the wavelength of the tortuous motion (*L*):

(6)

Based on the above, we can conclude that the frame force will act on the axle neck end in one direction with period T and every half of the period in the opposite direction.

The results of calculation of λ, T, L, and 0.5T for the speed range from 25 to 200 km/h are given in Table 2.

**TABLE 2.** Frequency, period, half-period and wavelength of tortuous motion of a wheel set on the railway track

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **λ, s-1** | ***Т, s*** | **0,5*Т*, s** | ***L*, m** |
| 25 | 9.125668 | 0.688518 | 0.344259 | 17.2195 |
| 50 | 18.25134 | 0.344259 | 0.172129 |
| 75 | 27.377 | 0.229506 | 0.114753 |
| 100 | 36.50267 | 0.172129 | 0.086065 |
| 125 | 45.62834 | 0.137704 | 0.068852 |
| 150 | 54.75401 | 0.114753 | 0.057376 |
| 175 | 63.87968 | 0.09836 | 0.04918 |
| 200 | 73.00534 | 0.086065 | 0.043032 |

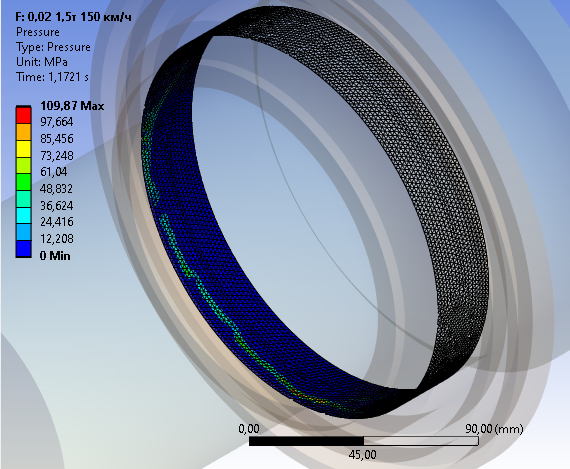
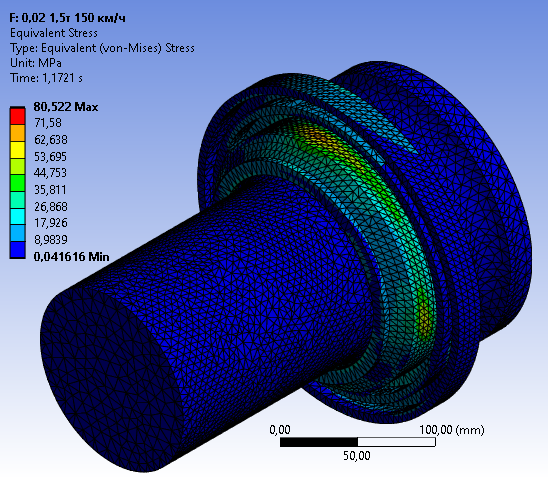
# RESULTS OF FINITE ELEMENT MODEL CALCULATIONS OF THE PRESS CONNECTION AND CONCLUSIONS ON THE WORK PERFORMED

To obtain the data set, a set of calculations (32 different combinations of initial data) was carried out, the processing of which resulted in the following:

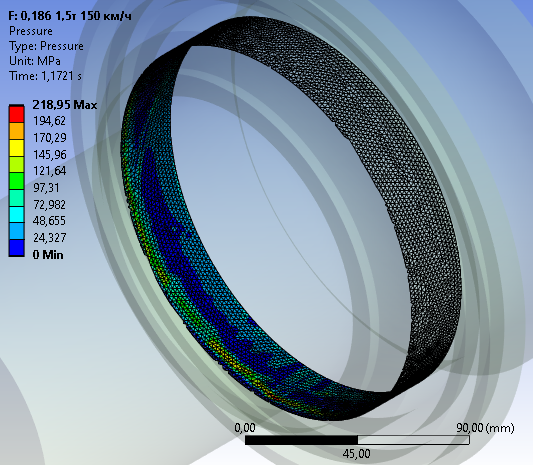
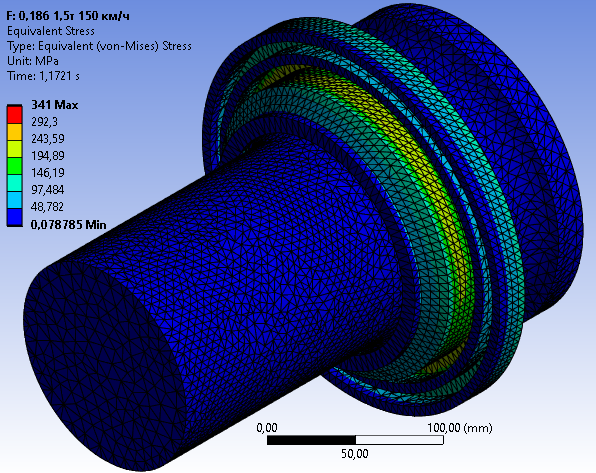
- Figure 3 shows the results of the model calculation for a loaded wagon at a speed of 150 km/h, a load of 1.5 and 16.5 tonnes, a tension value interval of 0.02 mm and 0.186 mm, taking into account the tortuous movement of the wheelset along the track;

- Figure 4 shows the distribution of stress-strain state on the outer surface of the labyrinth ring by width and contact pressure in the mating zone at the same initial data as in Figure 3.

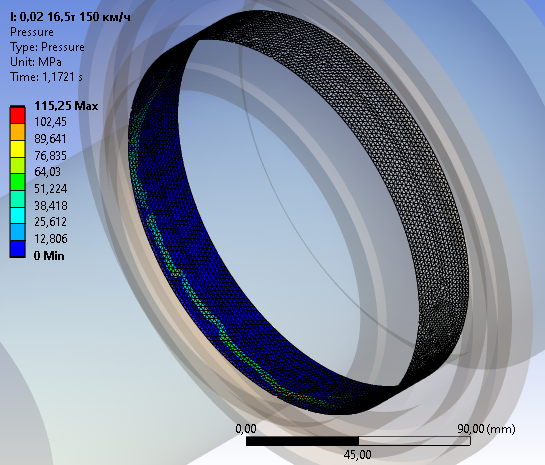
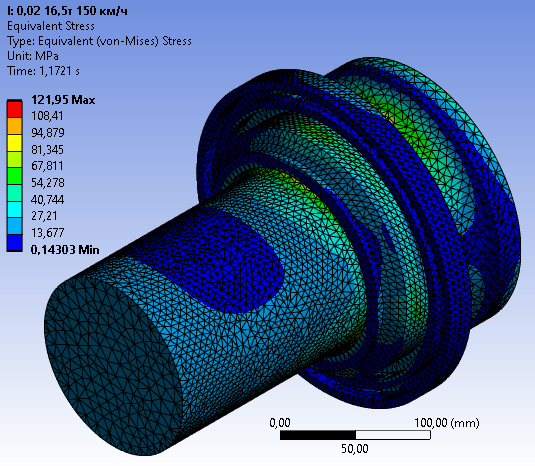
- Figure 5 shows the influence of the factor ‘tortuous movement of the wheelset’ for the labyrinth ring in the range of tension value from 0.020 to 0.186 mm and load from 1.5 tonnes to 16.5 tonnes when the speed is varied from 0 to 200 km/h.



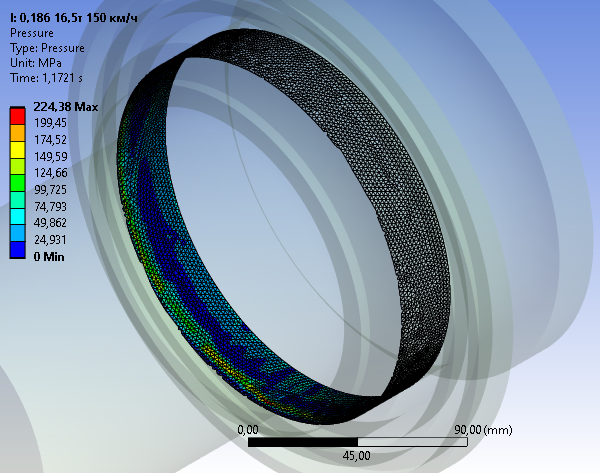
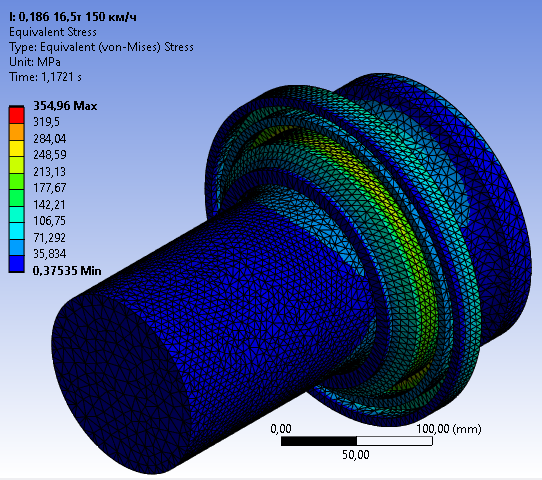
a)



b)

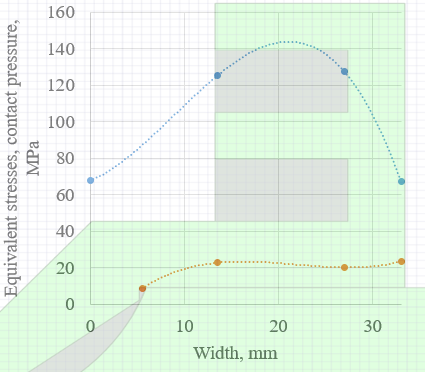


c)

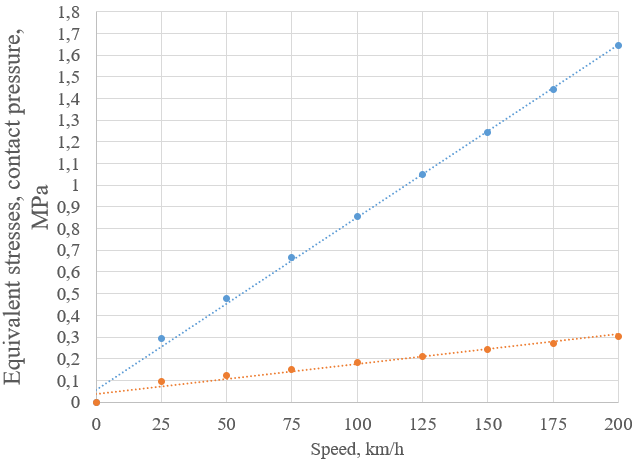


d)

**FIGURE 3.** Calculation results of equivalent stresses and contact pressure for a loaded wagon at a speed of 150 km/h, taking into account the tortuous movement of the wheelset:   
a – with 0.02 mm tension, load of 1.5 tonnes; b – with 0.02 mm tension, load of 16.5 tonnes; c – with 0.186 mm tension, load of 1.5 tonnes; d – with 0.186 mm tension, load of 16.5 tonnes.



**FIGURE 4.** Distribution of average equivalent stresses on the surface of the labyrinth ring and average contact pressure in the mating zone of the seating surfaces along the length of the mating for a driving speed of 150 km/h: 1 – average equivalent stresses   
(y = -0,007x3 - 0,0089x2 + 9,3869x + 17,365); 2 – average contact pressure (y = 0,0046x3 - 0,3021x2 + 6,1485x - 16,662)



2

1

**FIGURE 5.** Influence of the speed of movement taking into account the tortuous movement of the wheelset on the equivalent stresses of the labyrinth ring and contact pressure in the mating zone: 1 – equivalent stresses of the labyrinth ring surface   
(y = 0,008x + 0,0564, R² = 0,9977); 2 – contact pressure in the mating zone (y = 0,0014x + 0,0379, R² = 0,968)

# CONCLUSION

As can be seen from Figure 5, an increase in the speed of the rolling stock, taking into account the tortuous movement of the wheelset, causes an increase in the stress-strain state of the labyrinth ring and contact pressure in the mating zone, but when determining the amount of tension in the mating through stress and contact pressure, there are significant differences, so in dynamics it is advisable to use the values of contact pressure to assess the strength of the press connection.

Further development of theoretical research on estimation of the strength of thermal press fit of the labyrinth ring taking into account the influence of operational factors on it is the estimation of the influence of the temperature of the axlebox unit on the strength of the press fit of the labyrinth ring at different loading and speed of the wagon.

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