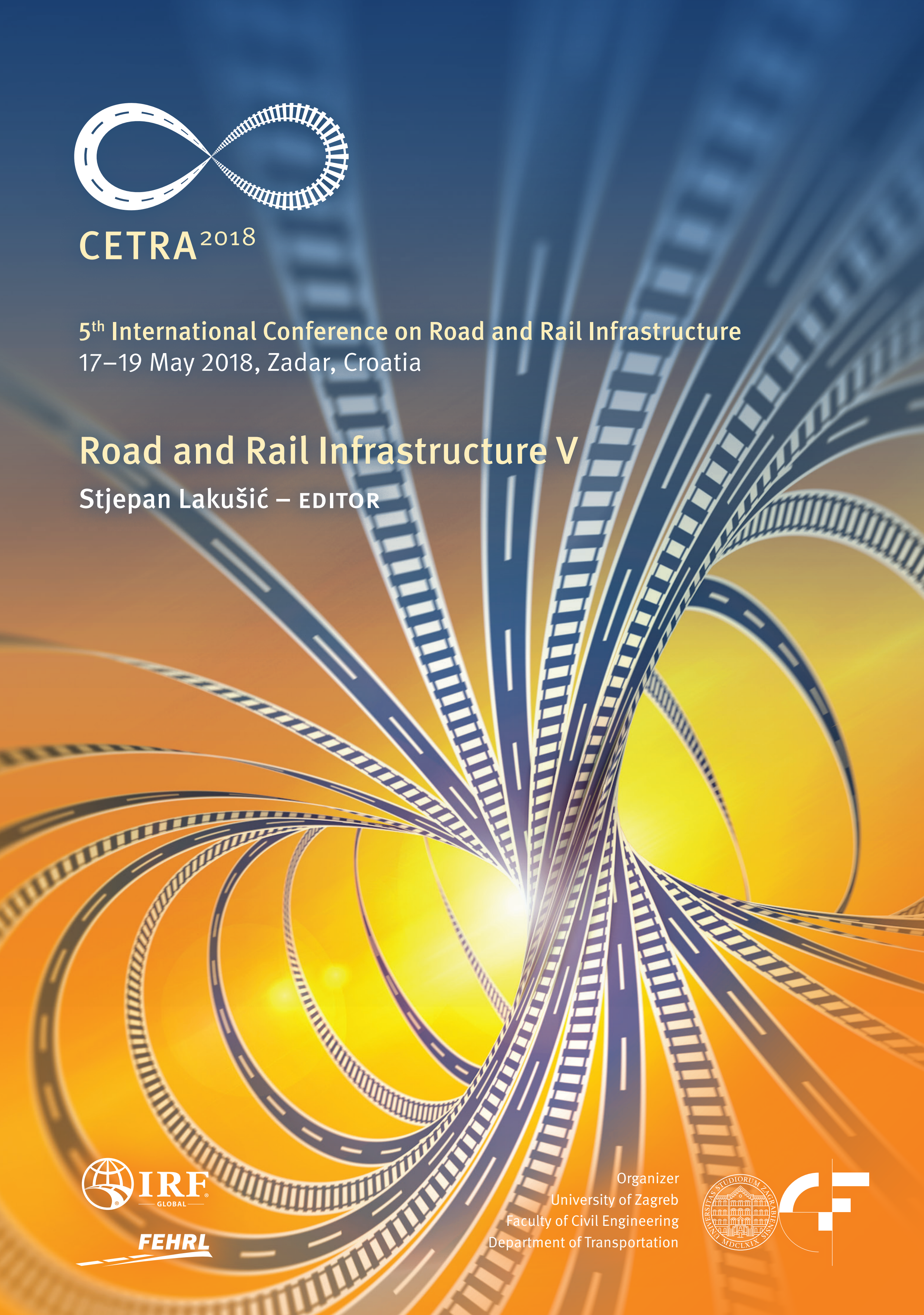

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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STRENGTH ASSESSMENT OF POWERED AXLE USING DIFFERENT CALCULATION METHODS

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Abstract

This paper is dedicated to the strength assessment of powered axle of shunting locomotive MDD-04, manufactured for Swiss market by Bulgarian Rolling stock manufacturer Express Service Ltd. Like many other components of the newly built locomotives, the axles are also subject to strict approval procedures. Based on geometrical characteristics of the axle combined with loads acting on the axle, as defined in European standard EN 13104:2009+A2:2012, strength assessment according to calculation method defined in this standard was performed. In this way obtained safety factor values were not satisfying, so it was decided to use Finite Elements Method for validation of first calculation results. Since the results obtained with first calculation method did not meet the requirements, and with the FEM they were satisfactory, an attempt was made to approve the design only with FEM. Although the results were satisfactory, the notified body demanded a change in the original design to be made, because of approval procedures prescribed in EN 13104. The results of the new calculations were more satisfying, so the powered axle could be approved by notified body. The new design of the axle was released for commissioning and use in new produced locomotives.

Keywords: strength, assessment, powered axle, FEM-analysis, calculation.

1 Introduction

Axles are one of the most important components in railway vehicles. Especially the powered axles are exposed to heavy loads such as bending and torsional moments which are caused by own weight of railway vehicle, traction and braking or by forces caused by motion in curves, in wheel/rail contact or inertial effects. Those loads occur at very high number of cycles (›109 which refers to more than 3 millions kilometres) during the service lifetime of an axle. Most axles are designed for service life of 30 years. During that time they have to safely operate which shall be ensured by a combination of safe life design and regular inspections. One of the main reasons for structural failure of railway axles is insufficient fatigue strength. The failure statistics show, that railway axles are usually safe. As well in Japan [1], in North America [2] and in Europe [3] failure cases of railway axles are rare. Beside insufficient fatigue strength, common reason of axle failures is over-heating of bearings combined with shearing up the axles next to the journal (“hot box” failure) as stated in [3]. Nevertheless, railway axles are safety–critical components. When an axle fails there is a high risk of derailment with potentially disastrous consequences. This is way the fatigue strength calculation in the design phase of each railway axle becomes important step in the prevention of failures. The requirements for calculation procedure for powered axles are defined in European standard EN 13104 [4] and requirements for the axle manufacturing are described in European standard EN 13261 [5]. The calculation methodology prescribed in EN 13104 [4] is based on traditional beam theory and represents the state of art for calculation of railway axles. This methodology is described in detail in the first section of chapter 2 of this paper. The initial design of powered axle of shunting locomotive MDD-04 was evaluated with this strength assessment method, as described in Chapter 3. The initial results obtained with this calculation method were not satisfying in regard to prescribed safety factor, so it was decided to use Finite Elements Method for validation of initial calculation results (Chapter 4). Currently, no obligatory FEM calculation is requested by related European standards [4, 5]. The results obtained by FEM-analysis show that initial design has prescribed strength. Although the results were satisfactory, a change in the original design had to be made, because of approval procedures prescribed in EN 13104 [4].

2 Calculation methodology according to EN 13104

In this chapter the calculation procedure for powered axles as defined in European standard EN 13104:2009+A2:2012 [4] is described. Geometrical characteristics of the axle combined with loads acting on the axle, as defined in standard mentioned above, were used for strength assessment of the axle. The results obtained by this calculation are given and discussed at the end of this chapter.

2.1 Object of the study and the initial calculation

The object of this study is powered axle of shunting locomotive MDD-04, manufactured for Swiss market by Bulgarian Rolling stock manufacturer Express Service Ltd. Based on technical drawings, provided by locomotive manufacturer, geometrical characteristics of the axle were defined. According to [4], Chapter 6, first step in calculation is to determine the geometrical characteristics of the various parts of the axle. This means that is necessary to identify the correct diameters in each cross-section of the axle in order to calculate stress values for given section. Also the distances between sections must be determined, especially the distances between attacking points of forces acting on the axle. They are used for calculation of bending moments. The axle design, determined cross-sections and distances between them are shown in Figure 1. Total of 16 cross-sections were determined together with their respective diameters. The following loads were applied to the axle:

- The forces of moving masses that generate bending moment M_x in each cross- section. It is calculated from the forces P_1, P_2, Q_1, Q_2, Y_1, Y_2 and F_i and represents the most unfavourable load case for the axle, as shown in Fig. 2. The values of these forces are calculated from mass m_1 according to formulas from Table 3 in [4]. The values of the bending moment M_x are calculated for different sections of the axle according to formulas from Table 4 in [4].
- The cross-sectional moments generated by braking. They consist of three components: M'_x (generated by the vertical forces), M'_y (generated by tangential forces at the wheels) and M'_z (generated by the horizontal forces). The formulas for the calculation of these moments were taken from Table 6 in [4] for the case “Two brake discs on the axle”.

After the calculation of the components of moments along each one of three principal directions is done, the resulting moment is calculated. The resulting moment M_R for the considered cross-sections is calculated according to point 5.6 from [4] and used for the calculation of the stresses according to eqn (1) [4]:

$$\sigma = \frac{K \cdot 32 \cdot M_R}{\pi \cdot d^3} \quad (1)$$

A fatigue stress concentration factor K (i.e. it takes into account the geometry and the material properties) for all considered cross-sections was calculated according to point 6.1 from [4]. In a cylindrical part situated on the surface of a solid axle, the stress concentration factor K is equal to 1. However, each change in section produces a stress increment, the maximum value of which can be found at the bottom of a transition between two adjacent cylindrical parts with different diameters or at the groove bottom.

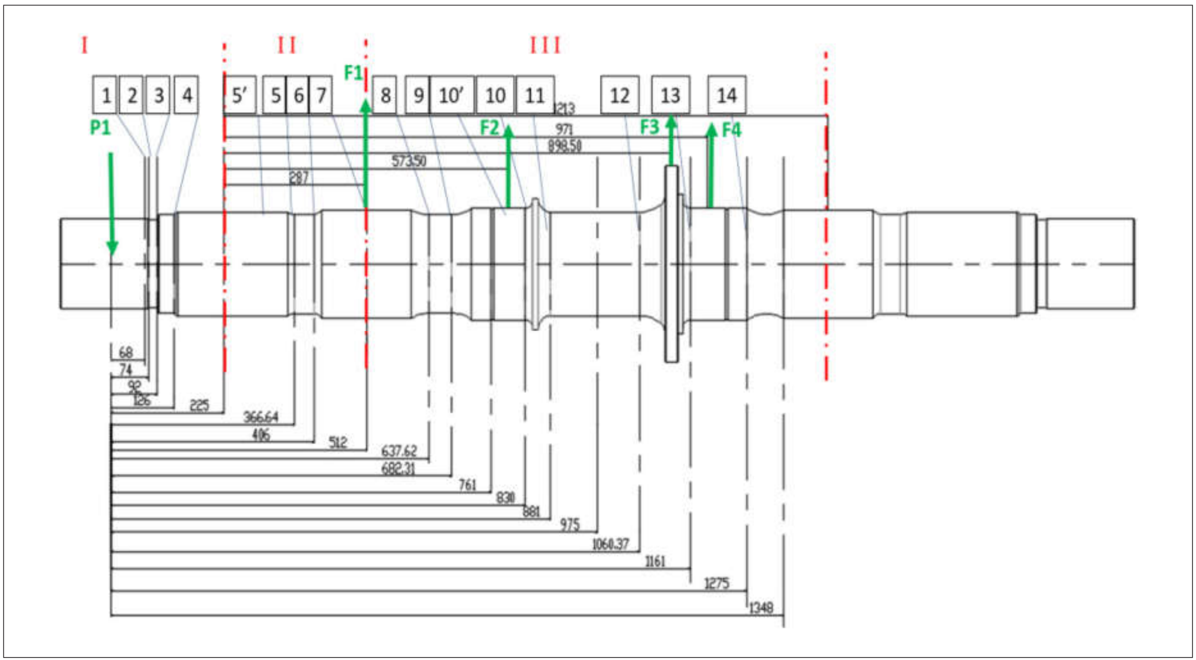

Figure 1 Powered axle of shunting locomotive MDD-04

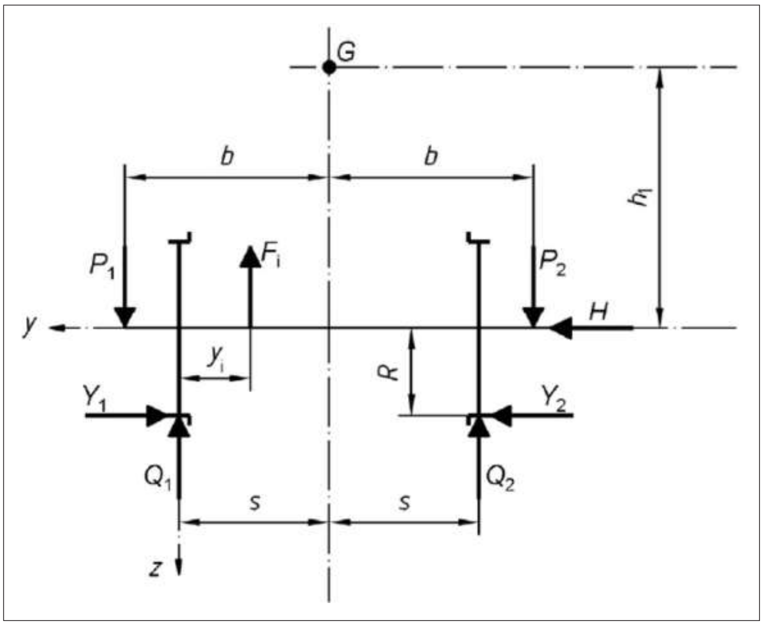

Figure 2 Loads acting on powered axle according to EN 13104 [4]

When a wheel, a disc, a pinion or a bearing is press-fitted (cold or hot) on a seat, diameter is to be assumed to be equal to the diameter of the hub or the bearing ring. For a collar or deflector or cross-bar, diameter is assumed to be equal to the diameter of the bearing seat, since the interference fit of these parts is very small. The calculated stress values are then compared with permissible fatigue strength values according to point 7.2 of [4] in order to determine the safety factors S according to the equation (2):

$$S = \frac{\sigma_{lim}}{\sigma} \tag{2}$$

The maximum permissible stresses are derived from the fatigue limit in rotating bending for the various areas of the axle and the value of a security coefficient "S", which varies with the steel grade. For the steel grade EA1N, which corresponds to the steel used for axle calculated, the fatigue limit values used for the design process are set out for a solid axle 200 N/mm² outside the fitting and 120 N/mm² beneath the fitting. Minimum value for a security coefficient "S" is set out to 1,3, unless measurements exist that demonstrate the loads are more precisely defined than those defined in this standard within an appropriate maintenance regime which maintains the track conditions, whereby a lower value of security coefficient S may be used if agreed between the designer and vehicle operator. However, the security coefficient S shall not be less than 1, 2. The calculation procedure described above was conducted on initial design of the axle. The calculation results for each cross-section numbered as shown in Fig. 1 for the coefficient of stress concentration K, stress σ and Security coefficient S are given in Table 1.

Table 1 Calculation results

Cross-section (From Fig. 1)	Coefficient of stress concentration K	Calculated stress σ [MPa]	Permissible stress σ_{lim} [MPa]	Security coefficient S
1	1	24.12	120	4.97
2	1.123	31.82	200	6.28
3	1.515	53.35	200	3.74
4	1.201	41.03	200	4.87
5'	1.031	100.44	120	1.19
5	1.200	136.23	200	1.46
6	1.045	119.32	200	1.67
7	1	89.40	120	1.34
8	1.003	117.91	200	1.69
9	1.004	116.94	200	1.71
10'	1	76.09	120	1.57
10	1.170	89.73	200	2.22
11	1.102	105.60	200	1.89
12	1.011	92.81	200	2.15
13	1.186	85.38	200	2.34
14	1.004	102.45	200	1.95

As it can be seen from the results in table 1, only one cross-section has a security coefficient less than minimum of 1,2 and it is the section 5' (beneath the press fit for the wheel) with value 1,19. Due to very small difference between permissible and calculated value of security coefficient, it was decided to perform strength calculation with other calculation method. The finite elements method (FEM) was chosen for validation of results obtained by calculation methodology according to EN 13104.

2.2 Calculation with finite elements method (FEM)

For the purposes of FEM-Analysis the 3D-model of the axle according to technical drawings provided by manufacturer was developed. The software used for modelling of the axle is SolidWorks and for FEM-Analysis SolidWorks Simulation was used. Tetrahedral solid finite elements with four Jacobian points were used for calculation. The total number of elements is 39914 and total number of nodes is 63931. The maximal size of elements is 38,9 mm and minimal size is 1,9 mm. The loads in all press fits on the axle were applied as evenly distributed pressure acting on the axle beneath wheels, brake discs, pinions and bearings. Figure 3 shows the distribution of pressure in press fit beneath the wheel (critical section 5').

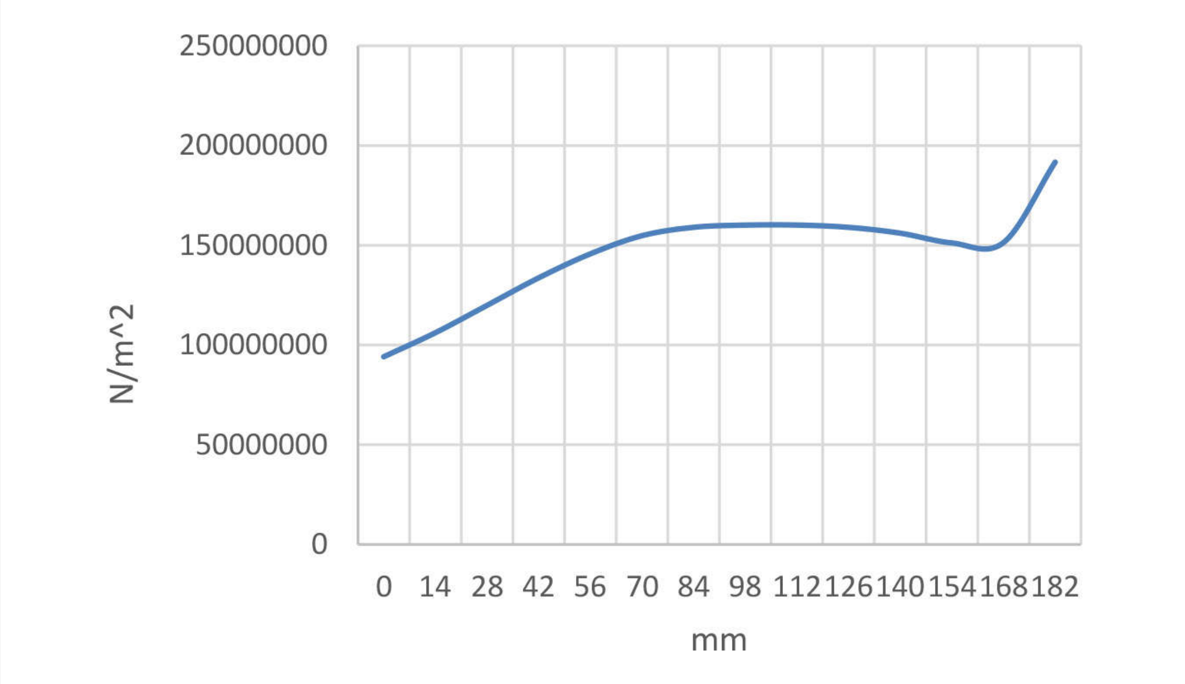

Figure 3 Distribution of pressure beneath the wheel press fit

Because the axle has a conical wheel seat, the pressure has its maximum value at the right end with increased diameter. Beside the contact pressure beneath press fit for wheel, all other loads were applied to the axle: braking forces, traction forces, inertia forces etc. In this case, when applying pressure in press fit before applying the forces described in previous subchapter, the permissible stresses should be set to the limits defined for solid axle outside the fitting – 200 N/mm² due to superposition of stresses. The result of FEM-Calculation is shown in Figure 4. The maximal stress value is 159,8 MPa. This stress is placed again in the same location – critical section 5'.

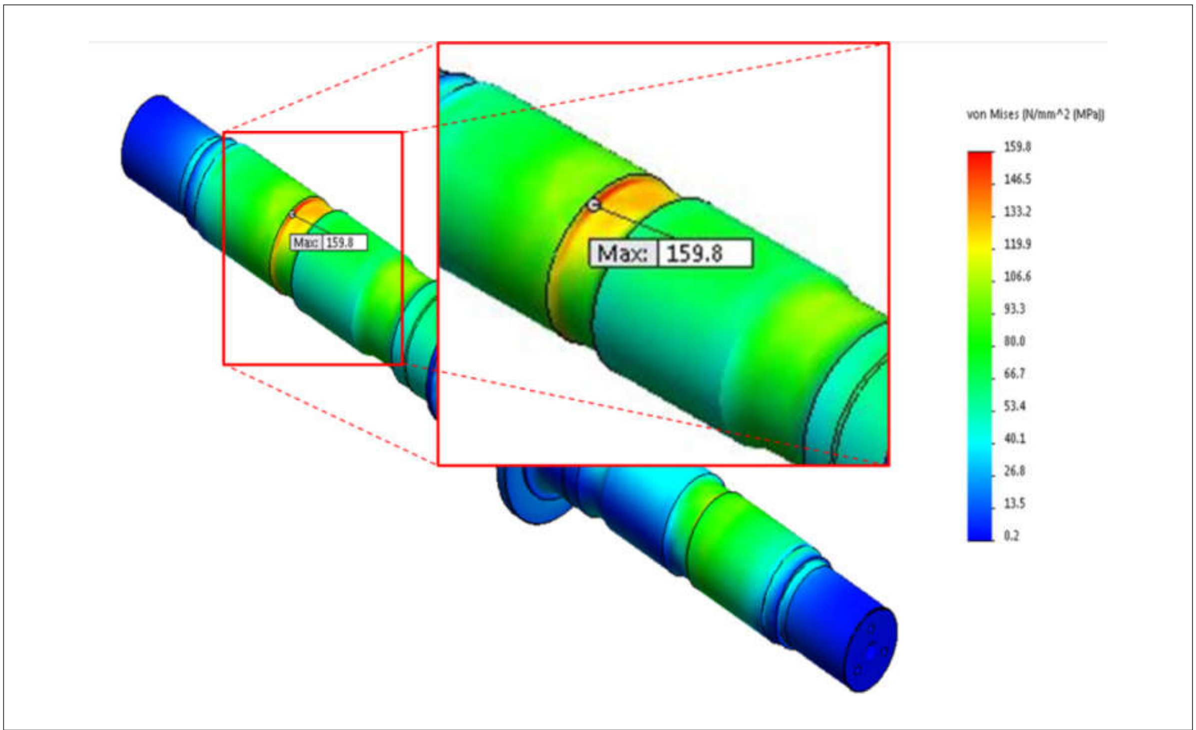

Figure 4 Calculation result of FEM Analysis

3 Comparison of results and new calculation

The results obtained by both calculation methods for the critical section 5' are compared in Table 2. The value of security coefficient obtained by FEM is 1,25 which is above minimal value of 1,2. The results of both calculations were presented to notified body in order to get the approval for the strength of the axle and admission for use in newly built locomotives. In the past, the calculation team could convince the notified bodies, that small overstepping of reference values are not critical for strength of different components of railway vehicles [6, 7]. Although the results obtained by FEM were satisfactory, notified body decided that change in the original design has to be made, because of very strict approval procedures prescribed in EN 13104 [4].

The only meaningful change in the original design of the axle was to increase the diameter of the conical part of the axle beneath the wheel press fit. The enlargement of this diameter by only one millimeter led to newly calculated security coefficient with value of 1,22, which was satisfactory for approval by notified body. The new design of the powered axle was released for commissioning and use in new produced locomotives.

Table 2 Comparison of calculation results

	EN 13104	FEM
Stress [MPa]	100.4	159,8
Permissible stress [MPa]	120	200
Security coefficient	1.19	1.25

4 Conclusion

Even with already proven calculation methods like FEM it is still not possible to get admission of some railway vehicle components. The "conservative" (as stated in [8]) calculation method for strength assessment of railway axles like defined in EN 13104 is still state of art. That may not be bad, considering the low failure rate of axles.

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