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ANALYTICAL CALCULATION OF HOLLOW RAILWAY AXLE IN ACCORDANCE WITH EN 13103

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Abstract *– The paper presents methodology for analytical strength calculation of hollow axles of railway vehicles. The considered methodology is defined by appropriate international standard EN 13103. The calculation procedure is demonstrated on the concrete example of hollow axle for axle load of 25 tons, and for normal track gauge of 1435 mm. Based on the appropriate authoritative loads, the equivalent stresses in the selected characteristic sections of the axle are determined. They should be compared with the corresponding permissible stresses for the considered sections of hollow axle determined on the basis of the endurance limits in certain sections and the corresponding safety factors. The results of the paper can be very useful for all those who deal with design and optimization of hollow axles of railway vehicles.*

Keywords – Hollow axle calculation, Railway vehicle, Strength calculation, EN 13103.

1. INTRODUCTION

The railway axles belong to the most significant parts in the railway traffic. A numerous experience from the past have shown that failures of these components have caused a large accidents and derailments with huge consequences [1]. In certain cases, failure of only one axle of certain vehicle in the train can cause derailment of the most part or whole train. Because of these facts, requirements for the strength of railway axles are very rigorous and they are precisely defined by international regulations. Given in mind distinctly dynamical character of their loads, railway axles must satisfy prescribed conditions related to the endurance limit. The main aim of design, calculation and production of railway axles is to prevent failure of the axle during the predicted operating life. It is well known from the past that Wöhler had developed his theory of material fatigue studying just failures of the railway axles [2]. To date, the methods of design and calculation of railway axles have significantly improved. Today, a common approach of design of railway axles and wheels is numerical calculation by usage of some of the modern software packages based on the finite element method (FEM) [3-6]. In addition, analytical methods are also important in the design of railway axles, especially in cases when is necessary to perform mathematical optimization of the axle design on the basis of precisely defined aim functions and restraints. One of the main aims of optimization of railway axles is reduction of their mass, which is non-suspended and has a large influence of dynamic behavior of railway vehicles. The approach which is in use for a long time is application of hollow axles. In this sense, the aim of this paper is to present methodology for analytical calculation of strength of hollow railway axles in accordance with the European Standard EN 13103 [7].

2. REPRESENTATIVE LOADS

The representative loads for railway axles calculation are defined by international standard [7]. The principal scheme of these axle loads is shown in Fig. 1, while expressions for determination of loads values for non-guiding axle of normal track gauge are given below.

Forces which act on the axle journals are [7]:

$$P_1 = \left(0.625 + 0.075\frac{h_o}{b}\right) m_1 \cdot g \tag{1}$$

$$P_2 = \left(0.625 - 0.075\frac{h_o}{b}\right) m_1 \cdot g \tag{2}$$

$$H \approx Y_1 - Y_2 \tag{3}$$

Reactive forces in the wheel-rail contact are [7]:

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$$Y_1 = 0.3 \cdot m_1 \cdot g \qquad (4)$$

$$Y_2 = 0.15 \cdot m_1 \cdot g \qquad (5)$$

$$Q_1 = \frac{1}{2s}\left[P_1(b+s) - P_2(b-s) + (Y_1 - Y_2)\cdot R\right] \qquad (6)$$

$$Q_2 = \frac{1}{2s}\left[P_2(b+s) - P_1(b-s) - (Y_1 - Y_2)\cdot R\right] \qquad (7)$$

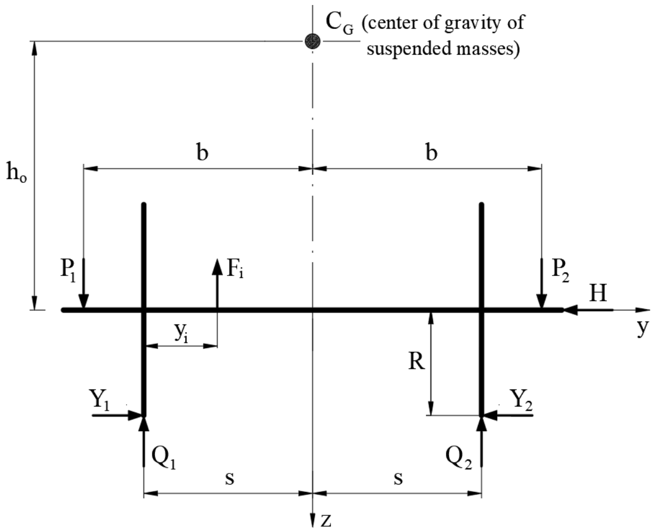

Fig.1. The principal scheme of axle loads

As can be seen, the main parameter for determination of given forces is mass per one axle (m_1), which is defined as difference between axle-load mass (m_{al}) and wheelset mass (m_{ws}):

$$m_1 = m_{al} - m_{ws} \qquad (8)$$

The standard also takes into account the influences of braking forces and inertia forces (F_i) on the axle strength.

3. CONSIDERED HOLLOW AXLE

The hollow axle for axle load of 25 t is considered in this paper. This axle is shown in Fig. 2. The characteristic parameters necessary for calculation of given axle are:

m_{ws}=1400 kg – wheelset mass;
h_o=1900 mm – supposed height of center of gravity of suspended mass for loaded wagon;
$2b$=2000 mm – distance between axle-box cases;
$2s$=1500 mm – distance between nominal rolling circles;
D=920 mm – nominal wheel diameter;
F_i=0.

The more details about production of the considered axle are given in [8].

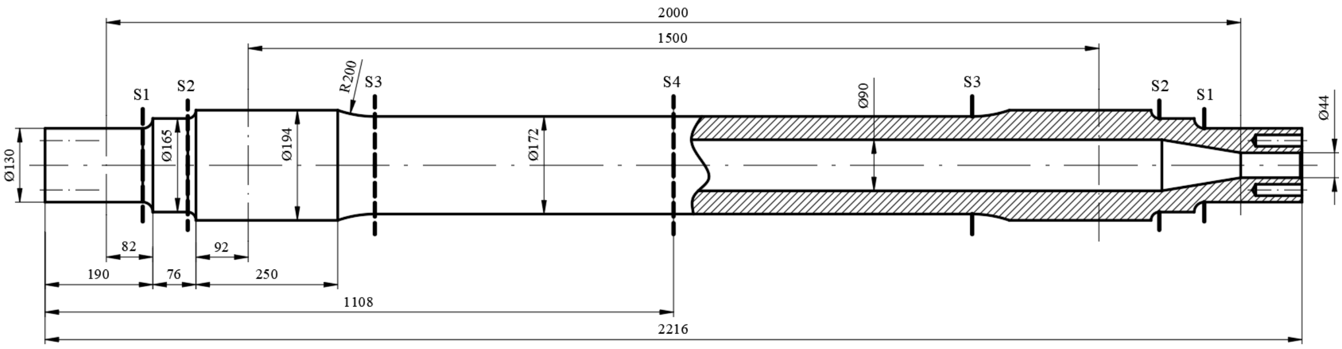

Fig.2. Considered hollow axle [8]

4. CALCULATION RESULTS

The values obtained on the basis of equations 1-8 are shown in the Table 1.

Table 1. The values of representative loads for axle calculation

m_1=23600 kg	Y_1=69.45 kN
P_1=177.69 kN	Y_2=34.73 kN
P_2=111.71 kN	Q_1=199.33 kN
H=34.72 kN	Q_2=90.07 kN

4.1. Axle bending moments

The diagrams of bending moments in yz plane are shown in Fig. 3. The maximum bending moment in yz plane due to braking with two-sided shoe brake made of gray cast iron is determined from the following expression:

$$M_{xbr,\max} = \mu \cdot 0.3 \cdot F_s(b-s) \qquad (9)$$

where:
μ – friction coefficient (for braking with shoe brake made of gray cast iron μ=0.1);
$F_s = B_k \cdot P_w$ – braking force (B_k=0.75 is braking coefficient, P_w=122.625 kN is static load per wheel).

The maximum bending moment in xy plane (diagram in Fig. 4) due to braking is determined from the following expression:

$$M_{zbr,\max} = 0.3 \cdot F_s(b-s) \qquad (10)$$

The torsion moment of axle around y axis (diagram in Fig. 5) due to braking can be determined from the following expression:

$$M_{ytbr} = 0.3 \cdot P_w \cdot R \tag{11}$$

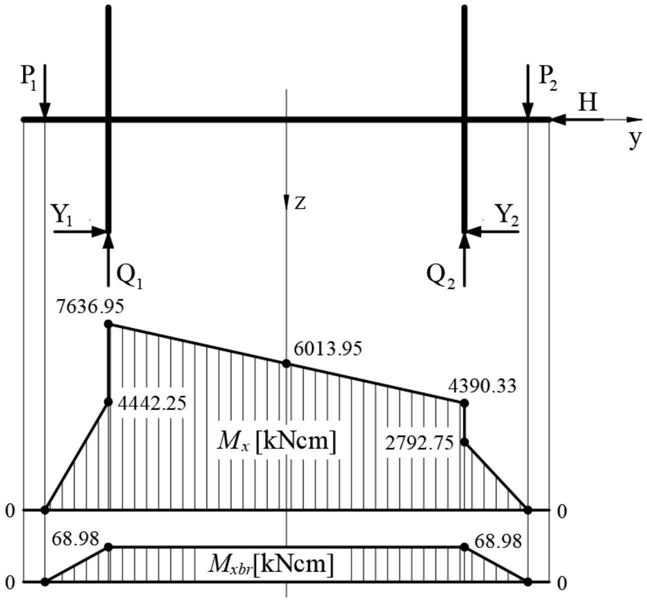

Fig.3. The diagram of bending moments in yz plane

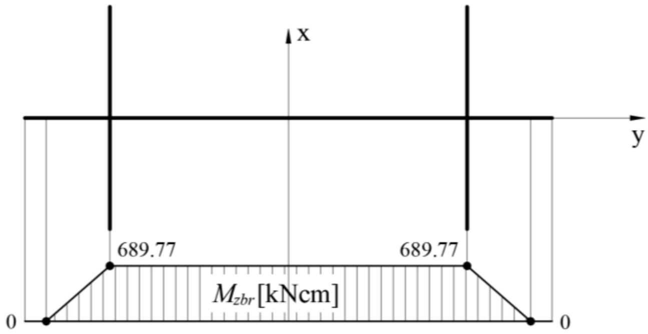

Fig.4. The diagram of bending moments in xy plane

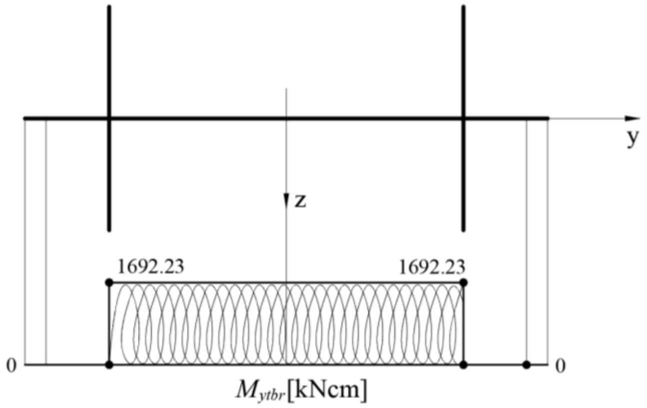

Fig.5. The diagram of bending moments in xy plane

4.2. Axle stresses

Four characteristic sections (S1, S2, S3, S4) for calculation of axle strength are selected, as shown in Fig. 2. In any point of the hollow axle, the equivalent stress is:

$$\sigma_e = \sqrt{\sigma^2 + 4\tau^2} \tag{12}$$

After taking into account the known expressions for normal and tangential stresses as well as the stress concentration factor, the expressions for equivalent stress at the outer and inner surface of the hollow axle $\sigma_{e,out}$ and $\sigma_{e,in}$ is obtained, respectively:

$$\sigma_{e,out} = S_k \cdot \frac{32 \cdot M_e \cdot d_{out}}{\pi\left(d_{out}^4 - d_{in}^4\right)} \tag{13}$$

$$\sigma_{e,in} = S_k \cdot \frac{32 \cdot M_e \cdot d_{in}}{\pi\left(d_{out}^4 - d_{in}^4\right)} \tag{14}$$

where:
S_k – stress concentration factor
$M_e = \sqrt{M_x^2 + M_y^2 + M_z^2}$ – equivalent moment
d_{out} – diameter of section at outer axle surface
d_{in} – diameter of section at inner axle surface

The stress concentration factor S_k is defined with the following expression:

$$S_k = A + 1 \tag{15}$$

where:

$$A = \frac{(4-Y)(Y-1)}{5 \cdot (10X)^{(2.5X+1.5-0.5Y)}} \tag{16}$$

$$X = \frac{r}{D}; \quad Y = \frac{D}{d} \tag{17}$$

The explanation of the parameters in expressions 17 is shown in Fig. 6.

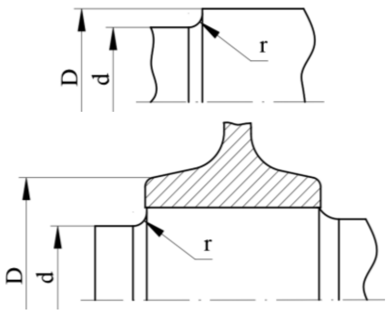

Fig.6. The explanation of parameters in expression 17

On the basis of expressions 13 and 14, the values of equivalent stresses in sections S1, S2, S3 and S4 are calculated. Obtained results of equivalent stresses are shown in the Tables 2–5.

Table 2. The results of equivalent stresses at section S1 of hollow axle

Equivalent moment	M_{e1} [kNcm]	1186.55
Stress concentration factor	S_{k1}	1.13
Equivalent stress at outer surface	$\sigma_{e,out1}$ [kN/cm^2]	6.63
Equivalent stress at inner surface	$\sigma_{e,in1}$ [kN/cm^2]	3.32

Table 3. The results of equivalent stresses at section S2 of hollow axle

Equivalent moment	M_{e2} [kNcm]	2646.92
Stress concentration factor	S_{k2}	1.54
Equivalent stress at outer surface	$\sigma_{e,out2}$ [kN/cm^2]	10.15
Equivalent stress at inner surface	$\sigma_{e,in2}$ [kN/cm^2]	5.53

Table 4. The results of equivalent stresses at section S3 of hollow axle

Equivalent moment	M_{e3} [kNcm]	7449.98
Stress concentration factor	S_{k3}	1.00
Equivalent stress at outer surface	$\sigma_{e,out3}$ [kN/cm^2]	16.13
Equivalent stress at inner surface	$\sigma_{e,in3}$ [kN/cm^2]	8.44

Table 5. The results of equivalent stresses at section S4 of hollow axle

Equivalent moment	M_{e4} [kNcm]	6351.16
Stress concentration factor	S_{k4}	-
Equivalent stress at outer surface	$\sigma_{e,out4}$ [kN/cm^2]	13.75
Equivalent stress at inner surface	$\sigma_{e,in4}$ [kN/cm^2]	7.20

The overview of obtained equivalent stresses in the considered sections of the hollow axle is given in the Table 6.

Table 6. The overview of obtained equivalent stresses in the considered sections of the hollow axle

Section	Equivalent stress	
	$\sigma_{e,out}$ [kN/cm^2]	$\sigma_{e,in}$ [kN/cm^2]
S1	6.63	3.32
S2	10.15	5.53
S3	16.13	8.44
S4	13.75	7.20

The obtained results should be compared with the corresponding permissible stresses that depend on the axle material and location of considered section. The permissible stresses for a given axle material and considered section are determined on the basis of the endurance limits and the corresponding safety factor.

5. CONCLUSION

The methodology for analytical calculation of strength of hollow axles of railway vehicles in accordance with international standard EN 13103 is exposed in the paper. The whole procedure is demonstrated on the concrete example of hollow axle for normal track gauge of 1435 mm and 25 tons of axle load. As expected, the most critical section of the considered axle is section S3 near to the pressed joint between wheel and axle, oriented towards the middle of the axle. The obtained results of the equivalent stresses should be compared with the corresponding permissible stresses that depend on the axle material and location of the considered section of hollow axle. The exposed procedure can be useful for all those who deal with design and optimization of axles of railway vehicles.

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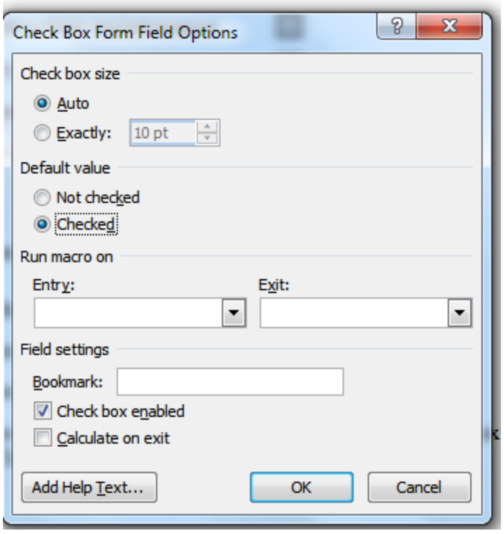

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