Mechanics Transport Communications
Academic journal
ISSN 1312-3823
issue 1, 2010
article № 0468
http://www.mtc-aj.com

STATE OF STRESS, CALCULATION AND THE EVALUATION OF QUALITY OF THE PRESS-FITTED ASSEMBLY BLOCKS WHEEL – AXLE

ALEKSANDROV Vladimir, VUKADINOVIC Vojislav
valeksandrov@sbb.rs, vojislav.vukadinovic@gmail.com

Vladimir Aleksandrov, M.Sc., Serbian Railway, Prote Mateje str. 40a, 11000 Belgrade
Vojislav Vukadinovic, M.Sc., Serbian Railway, Nemanjina str. 6, 11000 Belgrade
SERBIA

Abstract: *Regarding the safety of traffic, the assembly blocks are the most important assembly block of the railway vehicles. In this article, we shall consider the state of stress of the whelel hub and the axle hub seat, the basic principles of calculations concerning these assembly block and, finally, say something about the factors which affect or determine the quality of the press-fitted assembly block wheel–axle, and the procedure of the control of its quality.*
Keywords: *Railway vehicles, state of stress, calculation, control of quality.*

1. INTRODUCTION

Regarding the safety of traffic, the axle assembly blocks are the most important assembly blocks of the railway vehicles. The basic elements of every axle assembly block are the axle and two wheels. Additional elements may be the brake discs. Axle assembly block generally also includes lubricators with bearings. Formation of an axle assembly block is done by pulling on (press-fitting) of the wheels (and brake discs) onto the axle. Serbian railways and the majority of world's railways use the cold process of press-fitting. The wheel is gradually pulled on (pressed-fitted) onto its seat on the axle using the hydraulic press. Because of a lap (interference) between the diametar of the axle hub seat and the diametar of the opening of the wheel hub, after the press-fitting is finished, we get a firm longitudinally press-fitted assembly block capable of carrying (without deformations) all axial forces and torques which act upon the axle assembly block during exploatation. Normally, during the process of press-fitting on the conjugal elements (the axle and the wheel) act upon each other, causing certain stresses of these elements. In the further part of this article, we shall consider the state of stress of the wheel hub and the axle hub seat, the basic principles of calculations concerning these assembly blocks and, finally, say something about the factors which affect or determine the quality of the press-fitted assembly block wheel – axle, and the procedure of the control of its quality.

2. GENERAL CONCEPT OF THE PRESS-FITTED ASSEMBLY BLOCKS ON THE AXLE ASSEMBLY BLOCKS

Press-fitted assembly blocks realize a firm connection of the two elements, inner (internal) and outer (external), due to the sliding resistance which exists because of the pressure on the contacting surfaces. A firm connection of the two elements is made by impressing the "shaft" (male part) into the "opening" (female part) the diameter of which is smaller than the diameter of the shaft (or vice versa, in case of assembling (mounting) of the axle assembly blocks) that is, forced assembling of parts made with the interference (lap). The resulting deformations, the widening of the opening and the contracting of the shaft, cause stresses of the elements and the pressure on their contacting surfaces.

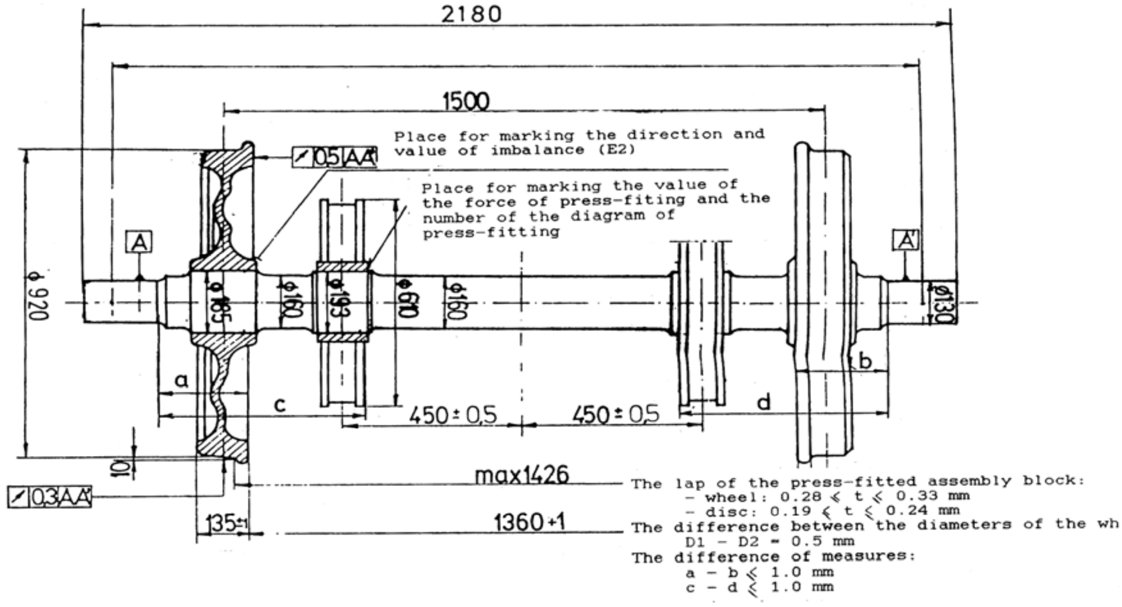

Figure 1. Geometrical measurements and the tolerancies of the axle assembly block with two brake discs, the diameter of the rolling circle ∅ 920 mm, the diameter of the axle journal ∅ 130 mm, the diameter of the brake disc ∅ 610 mm, product of te VALDUNES firm

In axle assembly blocks we apply the longitudinally (linearly) pressed assembly blocks which are made by forced impressing of the wheels onto the axle using the hydraulic press.

Figure 1. shows an assembly drawing of the axle assembly block, the product of VALDUNES firm (France), which is built (mounted) into the latest generation of the domestic passenger vehicles designed for speeds up to 200 km/h, product of GOSA.

Figure 2. shows a simplified transformation of the specific shape of the press-fitted assembly block wheel – axle (a), through the first approximation (b) into the shape of a classical linearly- press-fitted assembly block (c), suitable for further theoretical analyses.

The basic characteristic of every press-fitted assembly block is its carrying capacity (F), that is, the force that the pressed assembly block can carry without any intermediate, exclusively due to the sliding resistance on the contacting sufraces of the elements. A general formula for the carrying capacity of the press-fitted assembly block is:

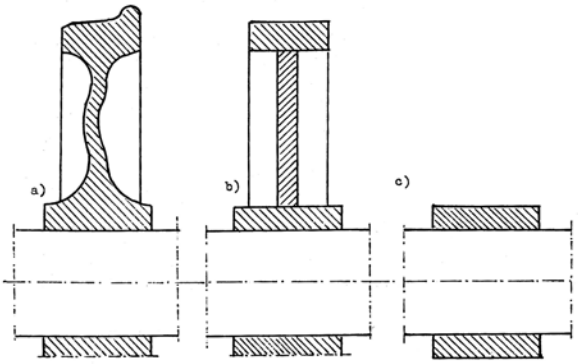

Figure 2. Transformation of the pressed assembly block wheel–axle (a), through the first approximation (b) into a classical press-fitteded assembly block (c)

(1) $F = S \cdot p \cdot \mu = \pi \cdot d \cdot L \cdot p \cdot \mu$ (kN),

where

d (cm) – is the diameter of the assembly block

L (cm) – the length of the assembly block

$S = \pi \cdot d \cdot L$ (cm^2) – contacting surface of the elements of the assembly block

p (kN/cm^2) – contact pressure

μ(–) – sliding resistance coefficient (coefficient of adhesive power)

Increase of the carrying capacity (F) can be achieved by the increase of length (L), contacting pressure (p), and the coefficient of adhesive power (μ) since the diameter (d) is, usually, predetermined (and usually is 185 mm). Contact pressure (p) depends on the difference between the diametar of the wheel hub seat and the diameter of the wheel hub opening, that is, on the lap (given, calculated, recommended or accepted). For testing the carrying capacity of the press-fitted) assembly block the minimum lap (interference), or the minimum contact pressure, is relevant, and for testing the stress, the maximum lap (interference), that is, the maximum contact pressure.

The dimensions of the press-fitted assembly bolck wheel–axle are shown in the figure 3.

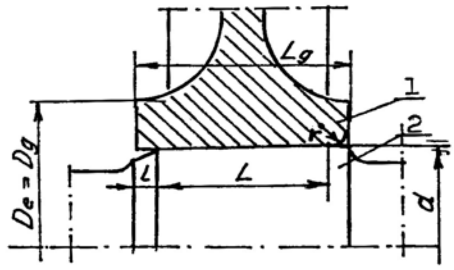

Figure 3. Dimensions of the press-fitted assembly assembly block wheel–axle

L = Lg – (l+r)

Lg – the length of the wheel hub

Dg – diameter of the wheel hub

l – the length of the tapered part of the axle hub seat

r – radious of the rounding of the edge of the wheel hub opening

d – nominal deameter of the assembly block

In practice, very often (almost always) for calculating the force of pulling on (press-fitting) of the wheel onto the axle, the empirical formula is used:

(2) $Fn = a \cdot D$ (kN)

where

D (mm) – is the diametar of the hub seat

a (kN/mm) – coefficient which dependes. on the lubricator and the element which is being pressed-fitted on (wheel or brake disc)

So that, for the press-fitting on of monoblock wheels and the use of molybdenum disylphide (MoS_2) as a lubricator, the value of the coefficient (a) is

$$a = 3.5 – 5.5 \text{ kN/mm}$$

For d = 185 mm and lubricating with Mos_2, the force of pulling on (press-fitting) (Fn) is within limitations:

$$0.6475 \leq Fn \leq 0.9250 \text{ MN}$$

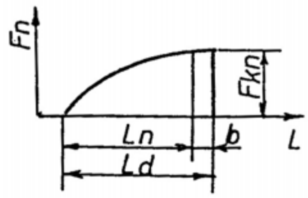

Figure 4. Diagram of press-fitting on of the wheel onto the axle

Fn – the force of press-fitting on (pulling on)
Fkn – the ultimate force of pulling on
Ln – the length of pulling on
Ld – theoretical length of the diagram of press-fitting
b – the length of the horizontal or inclined (downdards) part of the curve of press-fitting on the end of the diagram

The process of pulling on is performed as follows. Depending of the movements of the hub (1) along the hub seat (2), (see figure 3.), the force of press-fitting (pulling on) (Fn), (see figure 4.) increases. This force overcomes the friction force between the elements of the press-fitted assembly block and materialises work which is spent on the elastic and plastic deformations of the axle and the wheel hub. After the hub moves for one half of its length the intensity of the increase of the force of pulling on decreases due to the lessening of the rigidity of the wheel hub and a certain diminishing of the lap, (interference) due to the levelling (flattening) and the plastic deformation of the microirregularities of the conjugal (mating) surfaces of the press-fitted assembly block. From the moment of the emergence of the tapered part of the hub seat of the axle, until the end of the pulling-on process, the increase of the force of pulling on ceases.

The elements of the press-fitted assembly block are deformed after assembling: the outer element (wheel) is expanded, and the inner element (axle) is contracted (see figure 5).

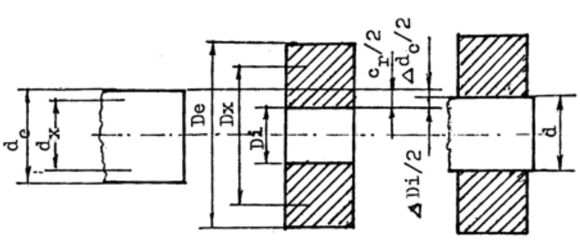

Figure 5. Deformations of ideal microgeometrical shapes after press-fitting

Deformations may be calculated according to the formulas of the theory of elasticity

(3) $$Dx = \frac{\psi^2 e}{me \cdot Ee\left(1-\psi^2 e\right)}\left[\left(\frac{De}{Dx}\right)^2 (me+1) + (me-1)\right] Dx \cdot p \cdot 10 (\mu m)$$

(4) $$\Delta dx = \frac{1}{mi \cdot Ei}(mi-1) dx \cdot p \cdot 10^4 (\mu m)$$

where

De (cm) – is the diameter of the outer (external) circle of the outer element (in our case the diameter of the hub)

Dx, d x (cm) – the diameters of the arbitrary circles on the outer and inner element

Di (cm) – diameter of the inner (internal) circle of the outer element (in our case the diameter of the hub opening)

d e (cm) – outer (external) diameter of the inner element (in our case the diameter of the axle hub seat)

d (cm) – the diameter of the press-fitted assembly block (nominal diameter)

Ee, Ei (kN/cm^2) – modulus of the eleasticity of material of the outer, or inner element

m e, m i – Poisson's number for outer, or inner element p (kN/cm^2) – contact pressure

$\psi e \frac{Di}{De}$ – relation of the diameters of the outer element

On the tangent (contacting) circle (Dx = Di), that is, (d x = d e), so that the deformations of the outer, or the inner element are

(5) $$\Delta Di = \frac{(me+1)+(me-1)\psi^2 e}{me \cdot Ee\,(1-\psi^2 e)} \cdot Di \cdot p \cdot 10^4 (\mu m)$$

(6) $$\Delta de = -\frac{mi-1}{mi \cdot Ei} \cdot de \cdot p \cdot 10^4 (\mu m)$$

that is

(7) $$\Delta Di = e \cdot Di \cdot p \cdot 10^4 (\mu m)$$

(8) $$\Delta de = -\frac{mi-1}{mi \cdot Ei} i \cdot de \cdot p \cdot 10^4 (\mu m)$$

where

(9) $$\xi e = \frac{(me+1)+(me-1)\varphi^2 e}{me \cdot Ee \cdot (1-\varphi^2 e)} (cm^2/kN)$$

deformation factor of the outer part, and

(10) $$\xi i = \frac{(mi-1)}{mi \cdot Ei} (cm^2/kN)$$

deformation factor of the inner part.

According to the figure 5, the sum of the deformations of both elements is equal to the calculated lap (interference), that is:

(11) $c\,r = \Delta Di + \Delta De\,(\mu m)$

If we ignore the values of the deformations, as very small compared with the values of the diamteres, we can accept that

$$Di \approx d\,e \approx d,$$

so we can express the calculated interference (lap) as:

(12) $c\,r = (\xi e + \xi i) \cdot d \cdot p \cdot 10^4\ (\mu m)$

where

d (cm) – is the nominal contacting (tangent) diameter.

From the formula (12) we can calculate the contact pressure (p) caused by calculated interference (lap) (c r)

(13) $p = \dfrac{c\,r}{(\xi e + \xi i)d} \cdot 10^{-4}\,(kN/cm^2)$

For determining the guaranteed carrying capacity of the press-fitted assembly block, the minimum contact pressure (p min) is relevant, which corresponds to the minimum calculated lap (interference) (c r min)), while the checking of the state of stress the maximum contact pressure (p max) is relevant, which corresponds to the maximal calculated lap (interference) (c r max). In both cases we use the formula (13) putting in the suitable values of the calculated lap (interference).

Formulas for calculating deformations and laps (interferences) are relevant in the field of elasticity.

The real contact pressure is not equal on the whole lenght of the assembly block, because of the irregularity of the uneven areas on the contacting surfaces and because of the irregularity of the geometrical shapes of the elements. Contact pressure is considerably greater at the ends of the assembly block (see figure 6.) due to the increased resistance of the elasticity of the, free parts of the inner element which are outside the assembly block. Still, for practical calculations, with enough occuracy, we may consider that the contact pressure along the whole assembly block is equal, that is, constant.

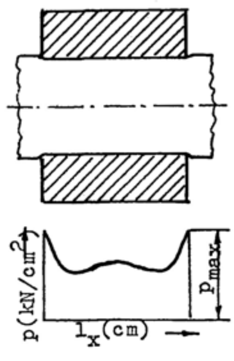

Figure 6. Diagram of the distribution of the contact pressure along the press-fitted assembly block

The tension of the elements of the press-fitted assembly block is greatest in the inner fibres of the outer element, or, in the outer fibres of the inner element (see figure 7).

Characteistical values of the stress of the assembly block are:

– on the inner (interneal) circle of the outer element

(14) $$\sigma te = \frac{1+e}{1-e}\cdot p$$

(15) $$\sigma re = -p$$

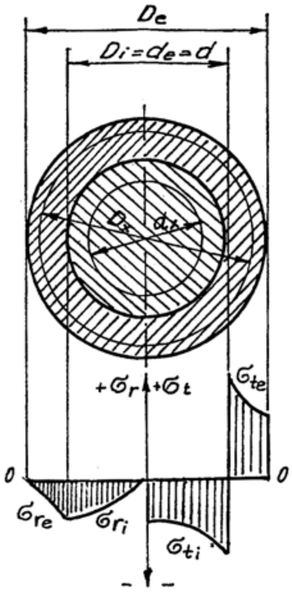

Figure 7. Stress diagrams of the elements of the elements of the press-fitted assembly block

Characteistical values of the stress of the assembly block are:

– on the inner (interneal) circle of the outer element

(14) $$\sigma te = \frac{1+e}{1-e}\cdot p$$

(15) $$\sigma re = -p$$

– on the outer (external) circle of the inner element

(16) $$\sigma ti = \sigma te = p$$

For the calculation, the stress of the most strongly conjugated (copuled) fibres is relevant.

The strongest "equivalent" tension (stress) of the outer element is

(17) $$\sigma e\ max = \frac{1+\psi^2 e}{1-\psi^2 e}\cdot p$$

and for the inner element

(18) $$\sigma i\ max = \frac{mi+1}{m\ i}\cdot p$$

In order that the stresses should stay within the field of elasticity,the following conditions must be fulfilled

(19) $$\sigma e\ max < \sigma Fe$$

(20) $$\sigma i\ max < \sigma Fi$$

where

Fe – is the limit of extension (stretching) of the material of the outer element

Fi – the limit of extension of the material of the inner element

The greatest permissible contact pressure may be determined from the condition that the limit of the extension of the material must not be exceeded, so that for the outer element

(21) $$\rho e\ max = \frac{\sigma Fe}{\xi e \cdot Ee}$$

and for the inner element

(22) $$\rho i\ max = \frac{\sigma Fi}{\frac{mi+1}{mi}} = \frac{mi}{mi+1} \cdot \sigma Fi$$

Taking into account everything mentioned above we can express the carrying capacity of the press-fitted assembly block in this way:

(23) $$F = \pi \cdot d \cdot L \cdot p \cdot \mu = \frac{\pi \cdot L \cdot \mu \cdot Cr}{e+i} \cdot 10^{-4} (kN)$$

that is

(24) $$F = \frac{\pi \cdot L \cdot \mu [c - 1{,}2(h\ e + h\ i)]}{e+i} \cdot 10^{-4}\ (kN)$$

where

L (cm) – is the length of the assembly block

μ (–) – coefficient of adhesive power

c (μm) – manufactured lap (interference) h e,h i h e, h I (μm) – the height of the uneven areas of the outer, or inner element

ξe, ξi (cm^2/kN) – deformation factor of the inner, or outer element

Carrying capacity defined in the above formula is called the calculated (arithmetical) carrying capacity. The actual – real carrying capacity (in assembled state) can be determined only by pressing off (separating) of the elements of the assembly block (see figure 8).

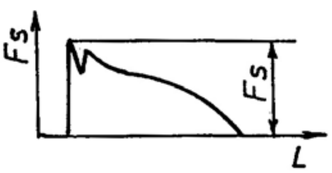

Figure 8. The diagram of dismantling (pulling off) of the wheel from the axle

In pulling off of the wheel from the axle, the beginning of the process (until the movement) is characterized by abrupt increase of the force (Fs) due to the greater value of the friction coefficient in the inactive state compared to the friction coefficient in sliding. Further in the process of pulling off, when the wheel hub begins to move along the axle hub seat, the force of pulling off begins to decrease due to decreasing of length of the press-fitted assembly block.

The actual carrying capacity of the press-fitted assembly block "in working state" differs from the actual carrying capacity in assembled state, so that it changes in time due to the different influences during exploatation (centrifugal forces, imbalanced weights, heat, impacts, etc.).

3. CALCULATIONS OF PRESSED ASSEMBLY BLOCKS

The calculation of the press-fitted assembly block amounts to the determination of the required lap (interference) for the wanted carrying capacity, or, as a rule, on checking the carrying capacity for accepted (or calculated) lap. In both cases it is necessary to check the stresses of the elements of the press-fitted assembly block.

Using the accepted basic measures (De, d and L) we can, concerning the wanted carrying capacity, calculate the required lap (interference) and the other values in this order:

a) Determining auxiliary values

The relation of the diameters is calculated according to the following formula:

(25) $$\psi e = \frac{d}{De}$$

and the formation factors ξ e and ξ i according to the formulas (9) and (10).

b) The smallest necessary lap (interference)

On the basis of the carrying capacity which an assembly block, according to the regulations, should be guaranteed to carry – transport, we can determine the least necessary contact pressure

(26) $$p\ min = \frac{Fa}{S \cdot \mu a} (kN / cm^2)$$

where

Fa (kN) = is the axial force according to the regulations

$S = \pi \cdot d \cdot L$ (cm^2) – contacting surface of the press-fitted assembly block

μa (–) – coefficient of adhesive power

Using the (p min) we can find the smallest necessary lap (interference) (c r min) according to the formula (12) and the smallest manufactured lap (interference)

(27) $$c\ min = c\ r\ min + 1{,}2\ (h\ e + h\ i)\ (\mu m)$$

c) the biggest allowed lap (interference)

For finding (c max) it is necessary first to determine the largest allowed contact pressure (p e max) using the formula (21), or (p i max) using the formula (22). The relavant value is the smaller value of the allowed contact pressure (p max).

The largest allowed arithmetical lap (interference) (c r max) can be calculated using the formula (12), putting in the maximum value (p max) for the contact pressure (p), and the biggest manufactured lap (interference) according to the formula

(28) $$c\ max = c\ r\ max + 1{,}2\ (h\ e + h\ i)\ (\mu m)$$

d) Tolerances and the types of fitting

On the basis of the calculated values of the laps (c min) and (c max) we go on to determine the quality of treatment and the occuracy of measures for both elements of the press-fitted assembly block and the type of fitting of the elements of the assembly block.

e) Checking results

On the basis of extreme real laps (interferences) which suit the accepted type of fitting in ISO system, that is, on the basis of (c s max) and (c s min) it is necessary, finally, to check the value of the critical stress of the elements regarding the range of easticity and determine the guaranteed carrying capacity in order to compare it with the force to which the assembly block is exposed.

Checking the state of stress is done in the following order:

(29) c rs max + c s max – 1,2 (h e + h i) (μm)

$$\text{ps max} = \frac{\text{c rs max}}{(\xi e + \xi i)d} \cdot 10^{-4}\ (\text{kN/cm}^2)\quad (30)$$

(31) σ es max = ξ e · Ee · p s max < σ Fe (kN/cm^2)

(32) σ is max = 2 · p s max < σ Fi (kN/cm^2)

Checking of the carrying capacity is done in the following order:

(33) c rs min = c s min – 1,2 (h e + h i) (μm)

(34) $$\text{ps min} = \frac{\text{c rs min}}{(\xi e + \xi i) \cdot d} \cdot 10^{-4}\ (\text{kN/cm}^2)$$

(35) Fg = S · p s min. μ (kN) ≤ F (kN)

where

F = Fa

f) Data for assembling

The power of the press is determined by the formula:

(36) Fp = S · p s max · μ p (kN)

4. THE INDICATORS AND THE CONTROL OF QUALITY OF THE PRESS-FITTED ASSEMBLY BLOCK WHEEL–AXLE

As we have already stated, the axle assembly blocks are the assembly blocks of the railway vehicles which are of the utmost importance for the safety of traffic. The axle assembly blocks are under the influence of the horizontal and vertical, static and dynamic forces, which, during exploatation, tend to deform the parts of the assembly block, that is, to disturb strictly defined "geometry" or the rail-wheel relation, and, especially, the "geometry" of the axle assembly block.

One of the most important geometrical measures of the axle assembly block is the space between the inner front surfaces of the rim (circle, ring) of the wheel which moves between very narrow allowed limits. No considerable movement (increase or decrease of this space) of the wheels along their seats-on the axle is permitted. So, the wheel–axle assembly block must be firm and reliable enough.

There are many factors which affect the quality of the press-fitted assembly block wheel–axle. Those are, first of all: the quality of the assemblies-elements of the axle assembly block, the quality of workmanship and treatment of the same, the quality of control and assembling of the elements of the axle assembly block.

The best indicator of quality of the formation of axle assembly blocks (the pulling on of the wheels, and possibly, of brake discs onto the axle) are, after all, the diagrams of pulling on (press-fitting), their dimensions, as well as the shapes of the diagrams, especially the latter. The shape of the diagram of press-fitting "speaks most eloquently" about the quality of the press-fitted assembly block. According to their shape the diagrams can be classified as: ideal, good, acceptable and bad. Ideal diagrams are almost non-existant. Diagrams with certain (allowed) deviations from the "ideal" shape are considered good and acceptable. All diagrams which have such deviations from the ideal shape which cannot be accepted, are considered bad, and the assembly blocks with such diagrams are considered as waste.

For more details about the criteria for the evaluation of quality and reliability of the pulling on (press-fitting) of the wheels onto the axle, as well as a very expansive album of "good" and "bad" diagrams of press-fitting, the readers are refered to a work which is listed in bibliography under number (4).

However, in order not to deny the readers of this article some basic information about the evaluation of the quality of the press-fitted assembly block on the basis of the diagram of press-fitting, figure 9 shows an example of a "bad", and figure 10. and example of a "good" diagram with following explanations.

The ultimate forces of press-fitting in both cases (two different wheels on different axle assembly blocks) are within limits of the maximum and minimum calculated - arithnmetical value, that is:

$$0.61 < Fkn < 0.91 \text{ MN}$$

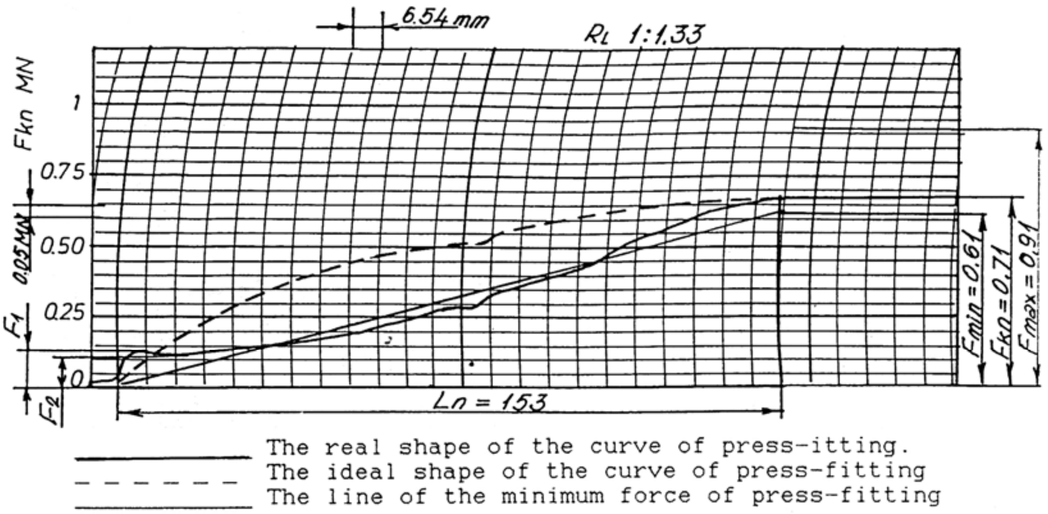

Figure 9. An example of a "bad" diagram of press-fitting of the wheel onto the axle

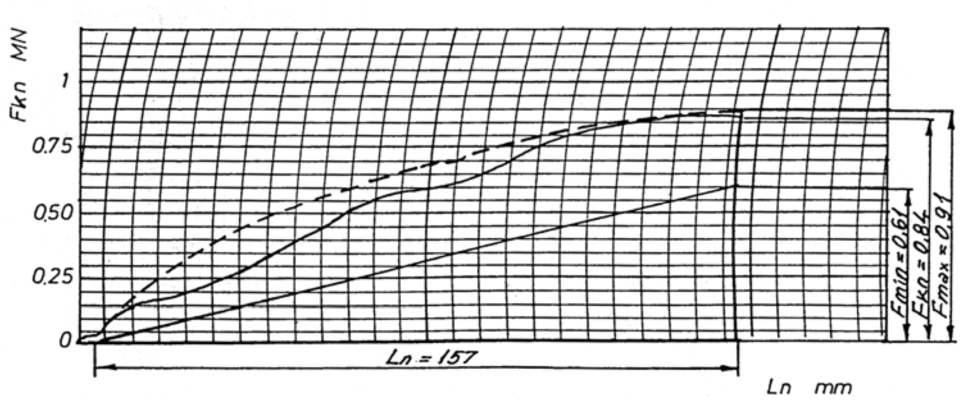

Figure 10. An example of a "good" diagram of press-fitting of the wheel onto the axle

The laps (interferences) in both cases are, also, between maximum and minimum calculated values:

$$0.28 \leq Cr \leq 0.33 \text{ mm}$$

Judging by the ultimate force of press-fitting and laps we could say that both diagrams are "good". But, by the analyses of the shapes of the diagrams of press-fitting and their comparison with the atlases of diagrams in the UIC regulations and technical books in this field, we come to the following conclusions:

a) The diagram in figure 9. does not comply with the regulations, that is, it has the following deformations from the norma1 shape:

– in the first half of the diagram the curve is pointing downwards (instead of upwards)

– the force of press-fitting decreases (instead of increasing) in one part of the curve, that is, the next value of this force is lower than the value of the preceeding one (F2 < F2)

– the abrupt jump of the force is noticable in the beginning of the press-fitting (instead of the gradual increase)

– the real curve of press-fitting is, in its considerable part, below the streight line of the minimum force of press-fitting (in other words, the force of press-fitting is less than minimum in a considerable part of the length of the assembly block).

The causes of the above metnioned deformations of the diagram shapes of the diagram of press-fitting are:

– the chamfer of the wheel hub opening in relation to the hub seat on the axle in press-fitting

– irregular execution of the tapered part in the centre of the axle hub or of the rounding of the rim of the opening of the wheel hub in the inner wheel hub front

– presence of a cone or a bend (linear humps) on the contact surfaces of the press-fitted assembly block

On the basis of what we have said above, we can conclude that such an assembly block is considered waste. The block from the diagram in figure 10 is not considered waste, although this block has certain, but acceptable, shortcomings.

5. CONCLUSION

Outside forces which act upon the axle assembly block during exploatation cause great and complex strains in its elements. Besides the strains caused by outside forces in the basic elements of the axle assembly block (wheels and axle) there are the so-called technological strains caused in the production process, or later, in their treatment and assembling which is, most usually, performed by linear pressing, that is, press-fitting.

Although the metodology of the calculations of the axle assembly blocks, that is, the analyses of the stress of its elements due to the influence of the outside forces is well known and has been thoroughly studied, that is not the case with the technological stresses, especially with the stresses caused by the press-fitting of the wheels (or brake discs) onto the axle. This work is dedicated particularly to this problem, that is, to the theory of calculation of stress in the axle hub seat and the wheel hub caused by their mutual influences, as well as, taking into account the influence of other elements of the wheel (disc and rim) to the character and intensity of these stresses, on which depends, to a large extent, the carrying capacity, the quality and reliability of the press-fitted assembly blocks on the axle assembly blocks which are of the utmost importance for the safety of the railway traffic.

BIBLIOGRAPHY

[1] Aleksandrov V., *Railway cars*, „Zelnid“ Belgrade, 2000.

[2] Aleksandrov V., *Maintenance of the railway vehicles* „Zelnid“ Belgrade, 2000.

[3] Aleksandrov V., *Maintenance of the axle assembly blocks* (manuscript monography), Be1grade 2006.

[4] Aleksandrov V., *Criteria for the evaluation of quality and reliability of cold pulling on of the monoblock wheels onto the axles*. Collection from the VZS conference, Belgrade 1998.

[5] Atmadzhova D., *Calculation of the wagon wheelsets*, Higher School of Transport, Department Transport equipment, Sofia, 2008 http://tt.vtu.bg/learning/YPR_2.pdf

[6] Vitas D., *The basis of the mechanical constructions*, „Naucna knjiga“ Belgrade, 1973.

[7] Шадур Л., *„Рашчет вагонов на прочност“,* „Машиностроение“, Москва, 1971.