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MOVEMENT ANALYSIS OF COOPERATING RAILWAY BUFFER HEADS

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Abstract: *The paper presents movement analysis of railway buffer heads. The analysis was based on recorded video of cooperating railway buffers during operation. In this paper is presented displacement of operating railway buffer heads in horizontal and vertical plane. Furthermore in paper is specified buffer stroke during operation with maximum speed of 40 km/h. Relating these values to the static characteristic of analyzed buffer it was possible to determine the values of longitudinal forces acting on buffer under determined conditions.*

Key words: *buffer, buffer head, movement analysis*

1. Introduction and purpose of research

Railway buffers and railway couplers are the only parts staying in contact in two adjacent railway vehicles during the operation. Railway buffers transmit the longitudinal forces acting on moving rolling stock through the buffer heads. Simultaneously they guarantee the smooth movement of railway, the proper railway dynamics in curves, the high level of safety for the passengers and the carried goods, and the vehicle's construction as well especially during overlapping the vehicles during braking (Sitarz and Gamon, 2013; Gamon, 2014; Hyung-Suk and Jeong-Seo, 2003; Baykasoglu et al., 2012a). Moreover, in case of crash of the vehicle with other vehicle or with obstacle, the construction of a buffer allows to dissipate part of energy of the crash. It guarantees the secure of carrying people and goods (Baykasoglu et al., 2012b; Otlacan et al., 2006; Craciun and Mitu, 2011). In the literature of subject were described a lot of constructions of the railway buffers which allow to dissipate the energy of crash. Among them are for example methods witch base on the hydrostatic technology (Hyung-Suk and Jeong-Seo, 2003) or on the plastic deformation of steel constructions of the buffers, which is possible because of the special project of the construction (Otlacan and Kaposta, 2012).

As a result of the friction between the contact areas on the buffer heads of the adjacent vehicles, the buffer heads are subjected to wear (Fig. 1. and Fig. 2.), reducing a normative (according to EN 15551:2009) radius curvature of respectively 2750 mm for the buffers with the buffer stroke of 105 mm and 150 mm, and 1500 mm for the buffers with the buffer stroke of 100 mm (Sitarz and Gamon, 2013; European Standards, 2009; UIC, 2008a; UIC, 2008b). In the above-mentioned norm, in the annex I, was brought back the list of materials which are using to make the buffer heads. The materials are detail in the table 1.

Table 1. The list of the materials which are using to make the buffer heads (according to EN 15551:2009)

No.	Material	Hardened
1	S355J2+N	-
2	EN-GJS-600-3 EN-JS1060	-
3	EN-GJS-400-15 EN-JS1030	-
4	GS-52, 1.0552	-
5	Cf 35, 1.1183	> 450 HV30
6	S355J2+N	390-460 HV30
7	G25CrMo4V, 1.7218	-
8	34Cr4V, 1.7033	-
9	Oilamid [a] (PA6G + liquid lubricant)	-
10	Nylatron NSM [b] (PA6G + solid lubricant)	-
11	E300-520M Equivalent to GE320	165-215 HBS (NF F10-102)
12	L35GSM	> 500 HV30
13	35SG	> 500 HV30

[a] Oilamid is the trade name of a product supplied by Licharz GmbH, Buchholz, Germany.
[b] Nylatron NSM is the trade name of a product supplied by Quadrant Plastic Composites AG, Lenzburg, Switzerland.


Fig.1. Flattened center of buffer head


Fig.2. Wear of buffer head

Formerly, to repair and regeneration the buffer heads they were subjected to hardfacing process (Podemski and Marczewski, 1979), but because of the high costs of this solution, the difficulty and the time-consuming of the process it was gradually given up. At present the buffer heads are not regenerated, but only is minimizing their wear by applying lubricants (*Dokumentacja Systemu Utrzymania - Autobus Szynowy Typu 218Ma*, 2011). Flattening of the central part of the buffer head is the adverse phenomenon which has a negative influence on the durability, on the reliability of construction and on the safety of the carried people and goods. To minimalize this flattening, the buffer heads are covering by lubricants which have to reduce the friction coefficient and simultaneously they have to reduce the wear of the elements staying in the mutual contact. In Polish railway, in accordance with the Maintenance System Documentation, to protect the surface of buffer head are using graphite greases. Those greases usually contain 10% natural graphite. They are intend to mechanisms and friction surfaces, where is high pressure (and as a result there are contact stresses), low velocities of sliding against each other elements and temperatures which stay within the limits of from -20°C to +60°C. Those parameters correspond to real operation conditions, which was proved in this article, both as regards forces acting on squeezing elements (Hertz stresses) as well as the velocities of displacements of elements rubbing against each other. A low velocity and the buffer head alignment allowing to its more effective cooling causes that the problem of high temperature practically does not exist. However, this type of solution contains a lot of drawbacks. The most important are following: the necessity of periodic applying of lubricants, its negative influence on the environment or the method of covering the buffer heads with lubricant which often requires the presence of employee between the vehicles. Furthermore, the method which bases on periodical applying the lubricants on the surface of buffer head has another important drawback. Carrying (loose) material, the pollutants and the fractions from roadbed etc. might get to lubricate surface of buffer head, sticking to the lubricate, increasing simultaneously the wear out of the buffer heads as a result of contact, and in extreme cases they might provide even to damage the buffer head. For the purpose of increase the durability of buffer heads is assumed, that it would be beneficial to apply laser or galvanic cover with the proper material properties. They should allow to increase the period of the railway buffers operation without the necessity of regeneration or replacement the buffers to meet the normative requirements. To determine type and parameters of the process of applying the coat, its thickness, surface, chemical composition etc. it is necessary to determine the displacements of the cooperating buffer heads and to determine a value of the longitudinal force acting on them during the operation. For this purpose during these research were recorded working conditions of the railway buffers during the operation. It allowed to determine the range of the mutual movement of the buffer heads relative to each other in a vertical and horizontal plane. Furthermore, it allowed also to determine the displacements of the plunger relative to the base, which enables to determine a value of acting longitudinal force after the buffer characteristic analysis, which with the knowledge about the alignment of the buffer head allows as well to calculate the values of the contact stresses on the place of contact between both buffer heads.

2. Research methodology

The measurement of the buffer heads displacements was taken by the recording of their cooperation during the operation. For this purpose, on one of two staying in contact buffers of adjacent railway vehicles were mounted GoPro cameras which allow to record video with a resolution of 1920x1080p and speed 30 frames per second (GoPro Official Website). Cameras, mounted as shown in Fig. 3., allow to observe the displacements of the buffer head both in a vertical and horizontal plane.

The cameras were mounted on the buffer with a stroke 105 mm, equipped with rubber shock absorber with steel separators. The absorbing elements in this type of buffers are rubber rings placed coaxially, with the steel separators in shape of rings, which should be secure in the proper way (for example by the galvanization) from the rust, which can has negative influence on the rubber and its properties of the energy absorption. The buffer equipped with this type of shock absorber are widely use in railways due to its low costs of production, its desirable abilities of absorbing energy by the rubber, and easiness in changing its properties by matching the proper chemical composition. The most significant drawbacks of the buffers equipped with this type of the shock absorbers are ageing of the rubber separators (which need periodical exchanges) and the influence of temperature on the characteristic and the behavior of the rubber. The second of those problems is minimizing by the proper way of choosing the chemical composition. Section and static characteristic of this type of buffer are shown in Fig. 4. The adjacent buffer, which cooperates with the buffer equipped with the cameras, has the same parameters. To research were chosen constructions with possibly least worn out buffers.

Fig. 3. Mounting location of cameras on buffer

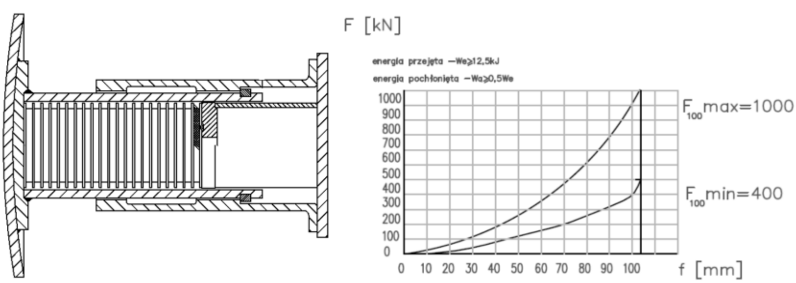

Fig. 4. Cross-section and static characteristic of rubber railway buffer

The considered buffers were mounted on empty self-dumping freight car series type 418V with a mass equal to 27680 kg. The cars serves first of all to carrying the loose materials (gravel, crushed stone, sand, ground) and they are using for this purpose in Polish railways. The unloading of this type of car is held by a 45-degree turn of the car body in one way or the other. The type of carrying materials and the way of its unloading have the significant influence on the wear out of the surface of the buffer heads. The carrying materials (especially during the unloading) might get to the lubricant which covers the buffer heads, simultaneously increasing in a large measure the friction coefficient μ of the both cooperating buffer heads and speeding up their wear out. In the result it might causes the decommissioning. The researches about the influence of this type of pollutants on the wear out of the material of buffer heads will be provided as a next step in the procedure of matching the optimal material, which can be used to covering the buffer heads to increase their durability. The records were carried out on the 15 km part of non-electrified railway line of the second category and 5th technical class of tracks. The view from cameras of cooperating buffer heads is shown in Fig. 5. and 6.

During the research were recorded ca. 66 minutes of film which shows the cooperation of buffers from all of the cameras. Because of very large amount of the recorded frames (ca. 118800 for each camera) was analyzed only chosen stages of the record. Those were six rides through the railroad switches with the different speeds, due to the biggest displacements of buffer heads. Exemplary value (for the horizontal displacements) measured during the operational research is shown schematically in Fig. 7.

Firstly was analyzed the recorded displacements of buffer heads relative to each other during passing the railroad switches by the rolling stock with three different speeds. Those were respectively 15 km/h, 20 km/h and 25 km/h. As a second step of analysis was checked the range of movement of the plunger relative to the base, which (using the buffer's characteristic) allowed to determine the longitudinal forces acting on moving rolling stock. In this case, most of all was analyzed recorded passages which show the biggest stroke, i.e. during the braking, when the vehicles were overlapping. The vehicles equipped with the buffers subjected to research were moving with a low speed. It eliminated sudden and strong hits between the buffer heads. In accordance with the standard EN 15551 (European Standards, 2009), the dynamic characteristic is a result of colliding the testing vehicle (Sitarz and Gamon, 2013; European Standards, 2009; UIC, 2008a; UIC, 2008b). In analyzed case, the cooperation of buffers was not generating these types of hits, but only "squeezing" the plunger to the base as a result of overlapping vehicles during the ride. Therefore, determined values of displacement were related to the static characteristic (Fig. 4.).

Fig. 5. View from camera mounted above the buffer

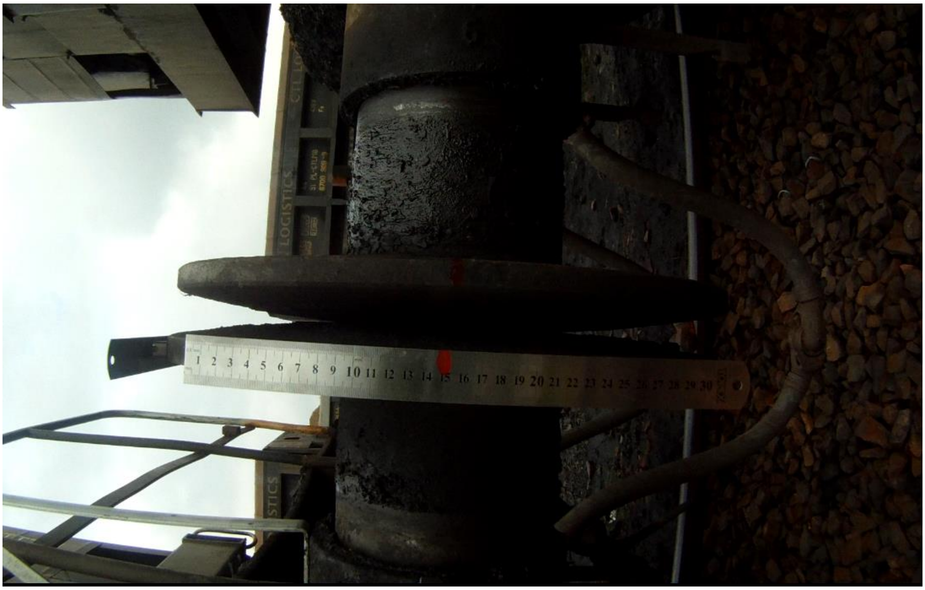

Fig. 6. View from camera mounted on the side of the buffer

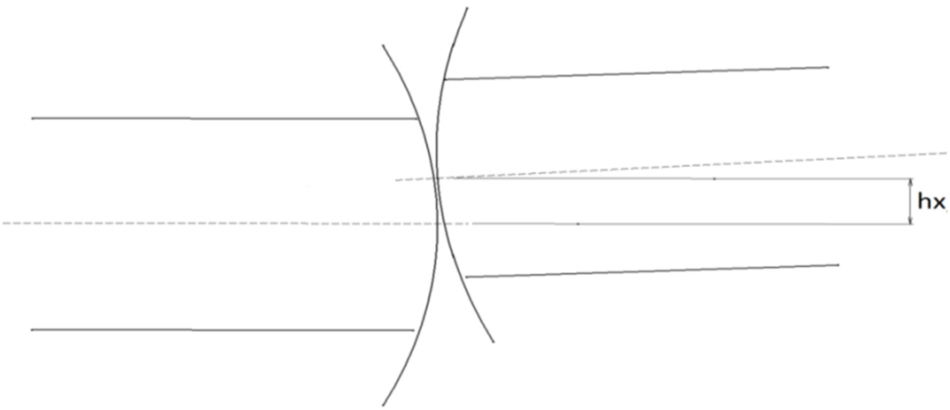

Fig. 7. Measured values of displacements; hx – lateral displacement [mm]

3. The movement analysis of buffer relative to each other

The results of movement (horizontal and vertical) analysis of buffer heads are shown in Fig. 8., 9., 10., 11., 12. and 13. Positive values for the horizontal displacements mean the deflection of the buffer head towards receding from the railroad axis. Positive values for the vertical displacements mean the deflection of the buffer head towards receding from the railhead. The first values (time = 0 second) presented in these charts show the deflections ca. 3 seconds before the buffer head has occurred under the railroad switch frog. For each speed were analyzed 12 seconds of recorded film, and the values of the deflections were measured every half second. In the Fig. 8 are shown the deflections of buffer head toward the horizontal direction and toward the vertical direction for speed of 15 km/h, in the Fig. 9. and 10. for speed of 20 km/h, and in the Fig. 11., 12., and 13., for speed 25 km/h.

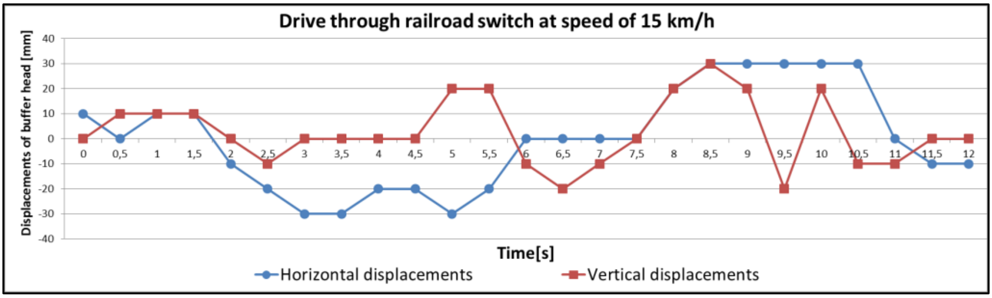

Fig. 8. Displacements of buffer head at speed of 15 km/h

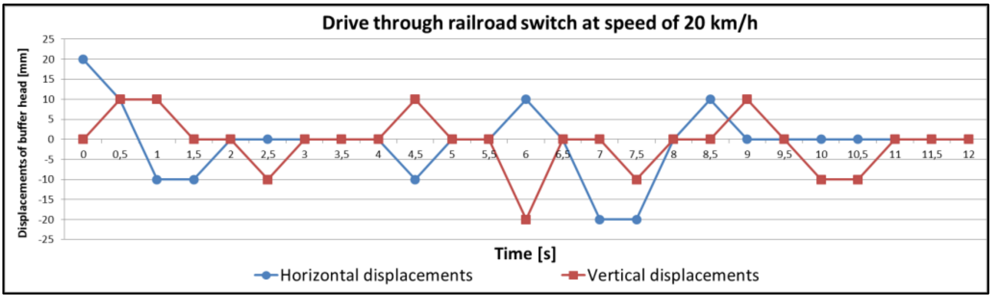

Fig. 9. Displacements of buffer head at speed of 20 km/h (first measurement)

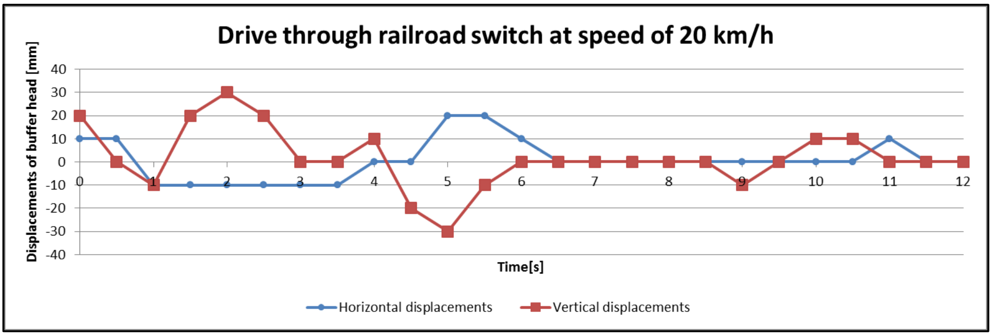

Fig. 10. Displacements of buffer head at speed of 20 km/h (second measurement)

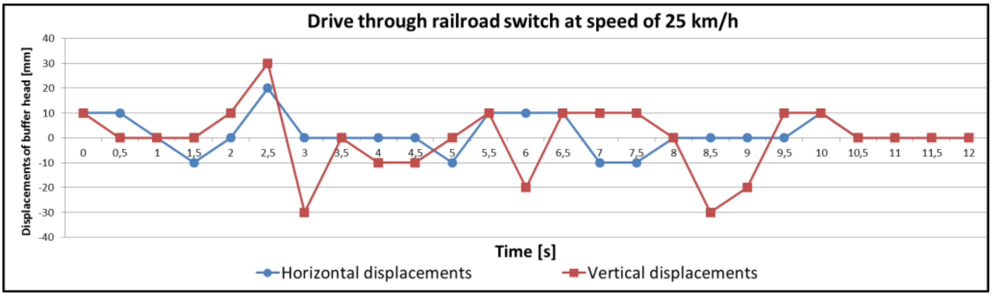

Fig. 11. Displacements of buffer head at speed of 25 km/h (first measurement)

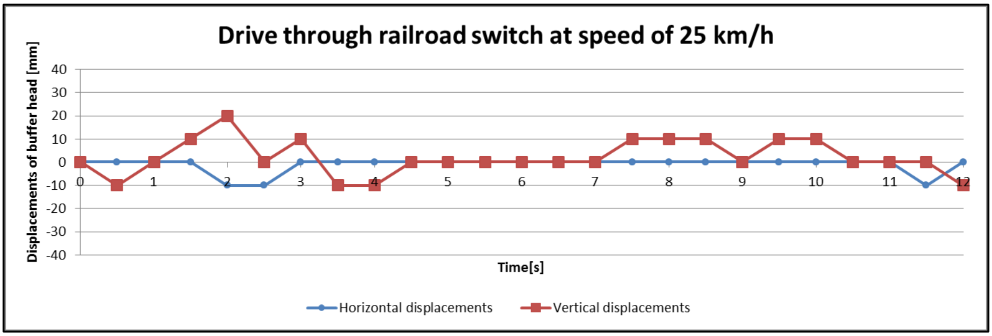

Fig. 12. Displacements of buffer head at speed of 25 km/h (second measurement)

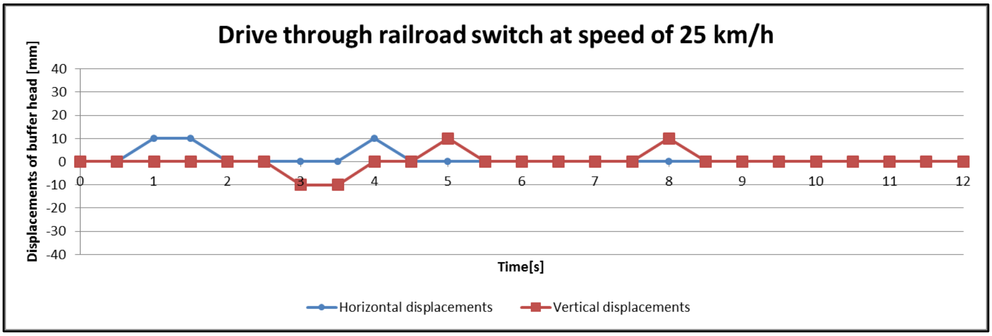

Fig. 13. Displacements of buffer head at speed of 25 km/h (third measurement)

Resulting from the Fig. 8., 9., 10., 11., 12. and 13. a maximal displacement (horizontal and vertical) of buffer heads to each other did not exceed 30 mm, regardless of the speed and the direction of the buffer head deflection. It allows to suppose that, as a result of friction of the buffer heads external surfaces, to the biggest wear is subjected the central part of the buffer head in a shape of circle (Fig. 2.) and the diameter of 60 mm. However, it is important to bear in mind that with increasing the wear of buffer head, this area is subjected to increase, reducing a normative radius curvature. Moreover, was observed that the range of displacements of buffer heads are similar to each other, regardless of speed during crossing the railroad switch. It suggests, that for determined conditions, a speed of vehicle is not a parameter which has a significant impact on a value of displacements of buffer heads to each other. Moreover, basing on the data gathered during recording the film about cooperating buffers it is possible to calculate their velocities of displacements relative to each other. After the analysis of Fig. 8-13 which show passing the railroad switches with different velocities it can be found that the average velocity of moving of the buffers toward the horizontal direction amounts ca. 0,0089 m/s, whereas the average velocity of movement of the buffers toward the vertical direction stays within the limit of ca. 0,016 m/s. It allows to draw a conclusion that the deflections of the buffer heads toward the vertical direction (which receding and approaching the buffer heads to railhead), are characterized by much larger dynamic and intensity. This is also confirmed by the wear out of track on analyzing part, which is characterized by the frequency appearing the different types of vertical irregularities. The obtained data about the velocity of moving buffer heads might be used as inputs to bench tests, allowing to choose the optimal material to cover the buffer heads in the purpose of maximize their durability.

4. The movement analysis of the plunger relative to the base

The results of movement (horizontal and vertical) analysis of buffer heads are shown in Fig. 8., 9., 10., On the basis of analysis of recorded footage, for determined conditions (empty self-dumping freight car series type 418V with a mass equal to 27680 kg, moving with a maximum speed of ca. 40 km/h) it can be observed, that the range of longitudinal movement of the plunger relative to the base does not exceed 50 mm, and for a most of time stays within limit of 0 - 30 mm. Relating these values to the static characteristic of analyzed buffer (Fig. 4.) it can be concluded, that the longitudinal forces acting on buffer under determined conditions do not exceed the maximal value of ca. 250 kN. Knowing the values of longitudinal forces acting on the buffers during the regular operation, the alignment of the buffer head and the material witch from it is made, it is possible to calculate the values of the maximal contact stresses σ_{dH} based on Hertzian theory formulas. In case of two spheres encountering each other, made of the same material (the analogy to real cooperate of two buffer heads) the formula for σ_{dH} is as it is presented below [Niezgodziński M.E. and Niezgodziński T., 2013]:

$$\sigma_{dH} = 0,388\sqrt[3]{PE^2\left(\frac{r_1+r_2}{r_1 r_2}\right)^2} \tag{1}$$

Assuming, that the spheres have the same radius $r_1 = r_2 = r$ (as it take place in fact), the equation can be wrote in the form:

$$\sigma_{dH} = 0,388\sqrt[3]{PE^2\frac{4}{r^2}} \tag{2}$$

where:
P – compressive force [N]
E – Young's modulus [Pa]
r – spheres radius (of the buffer heads) [m]

After inserting into the formula (2) the values of the alignment and the material of buffer head and the forces with values 250 kN, which was calculated as a maximal, acting by a very short time during the intensive overlapping the cars relative to each other, the values of the maximal contact stresses σ_{dH} are ca. 676 MPa. In case of the force with the value of 150 kN, which is maximal force observed during the regular operation and with the smooth movement of railway, the maximal values of contact stresses σ_{dH} are ca. 570 MPa. It means that the values of contact stresses which appears in the place of contact between the two buffer heads during the regular operation fluctuate from 0 to 570 MPa. The values calculated in this way allow to choose the proper parameters for the bench tests, which will allow to choose the material to cover the buffer heads to maximize their durability.

5. Conclusions

Based on the literature analysis and the results of carried out research, for determined conditions of operation, can be drawn following conclusions:

- The mutual horizontal and vertical displacement of buffer heads to each other during the operation do not exceed ca. 30 mm;
- The contact area between buffer heads increases with the wear of the buffer head surface.
- Under provided conditions of operation was concluded, that the displacements of buffer heads mainly depend on the track geometry;
- Under provided conditions of operation the stroke of analyzed buffer caused by mutual overlapping of vehicles do not exceed a value ca. 50 mm, and for the most of cases are within the range limit of 0 – 30 mm;
- Under provided conditions of operation the longitudinal forces acting on analyzed buffer do not exceed a value of ca. 250 kN, and for the most of cases are within the range limit of 0 – 150 kN;
- The velocity of displacements of buffers relative to each other is not high and amount to ca. 0,0089 m/s for the horizontal displacements and ca. 0,016 m/s for the displacement toward the vertical direction;
- The values of the maximal contact stresses σ_{dH} calculated basing on the Hertzian formula do not exceed the value ca. 676 MPa, and for the most of cases are within the range limit of 0-570 MPa.

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