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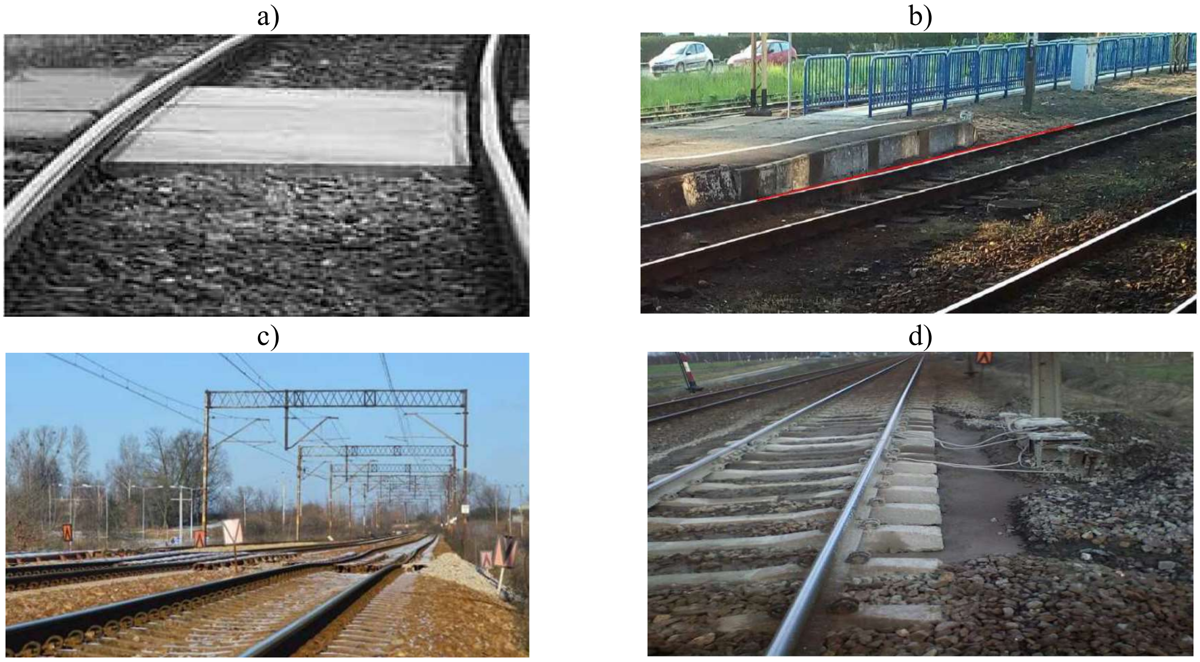
Influence of train wheel load and arising support imperfections of railway jointless track on its work during operating

Abstract: In the paper an analyses of chosen problems of influence of train wheel load and arising imperfections in jointless track on its work during operating are presented. A typical classification of arising imperfections in railway track is shown (on the basis of publications analysis and author's personal researches and analyses). In the paper appearing changes of stiffness between varied constructions (e.g. track–bridge, track–railway crossing) which in literature is defined as threshold effect are presented. An example of analyses of induced and intended imperfection in railway track with field investigations results and author's theoretical calculations are given. It is stated, that special attention shall be paid to wheel flat place significance as the source of following track structure degradation „from the top" and additional force loading railway track. In the paper a negative effects of considerable change of contact and support with rail roadbed are described.

Keywords: Track's imperfections; Unevenness simulation; Flat place on wheel

Introduction

During the operation of the contactless railway track, there is a different form of contact between the wheel and the rail, the foundation with bedding substrate or unfavorable, unintentional imperfections of contact between the track and the ground. Imperfection is understood in the work as imperfection, deviation of geometry or idealized properties and features (in railways most often identified with the unevenness of track or rail ground) [6-8, 10]. Under the influence of passing trains, imperfections of the wheel and rail foundation are created, which reduce the durability of the railway surface (Figure 1).



1. Examples of emerging imperfections in the railway track [21]

a) track inequalities in the level crossing area; b) deformations within the underpass (uneven support of the railway track, the original position of the track marked in red); c) inequality during the construction of the culvert; d) unveiling of railway sleepers

The existence of imperfection in the railway track leads to the progressive degradation of the railway surface, as well as to increased maintenance costs. Traffic safety and comfort of travelers is also reduced, which is why it is crucial to learn about imperfections (occurring in the ground or on the wheel of the rolling stock) and, above all, to know the significance of their possible effects.

A typical division of imperfections arising in the track can be presented in the following way (after analyzing the literature and the author's own experience) [1, 2, 5, 6, 10, 17, 18, 21]:

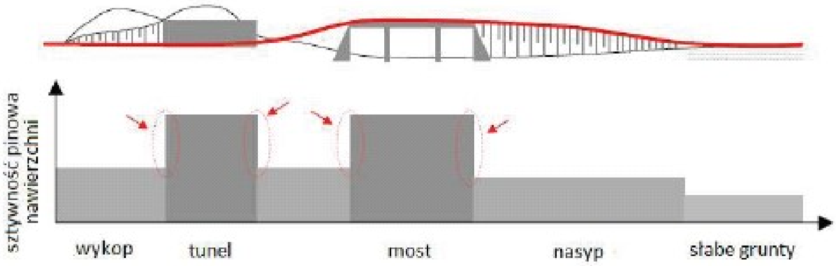
- imperfections resulting from the specificity of the railway (shown in Figure 2);
- imperfections due to human error;
  - arising from design mistakes;
  - arising from inadequate construction technology;
  - arising from incorrect or insufficient diagnostics;
  - arising from inadequate repair of the railway track;
- geometric imperfections in the railway track;
  - nierówności pionowe i poziome;
  - track twist;
  - changing the width of the track;
  - difference in height of rail tracks;
- rail imperfections
  - fatigue-contact damage;
  - internal defects;
  - cross-section wear;
- imperfections of railway sleepers:
  - imperfections of wooden foundations (e.g. cracks, damage to washers, spacers and screws);
  - imperfections of concrete foundations (e.g. scratches, cracks, fractures, crumbling of spacers);
- bedding imperfections;
- imperfections of the rolling stock wheel;
  - imperfections of the wheel's running surface;
  - imperfections of the surface of the periphery of the circle;
  - incorrect balance and ovalisation of the wheel;
- imperfections in the ground of the railway track;
  - step change in the susceptibility of the ground;
  - local unevenness of the ground;
  - substrate degradation.
- imperfections arising in the railway bedrock;
- imperfections due to human error;
- other imperfections (e.g. mining damage).

The paper analyzes selected issues of imperfections in the track:

- the issue of a step change in the stiffness of the surface and the resulting threshold effect;
- analysis and results of the author's research on developing intended imperfections in the railway track [16];
- the problem of wheel vehicle interaction with the rail non-contact rail track.

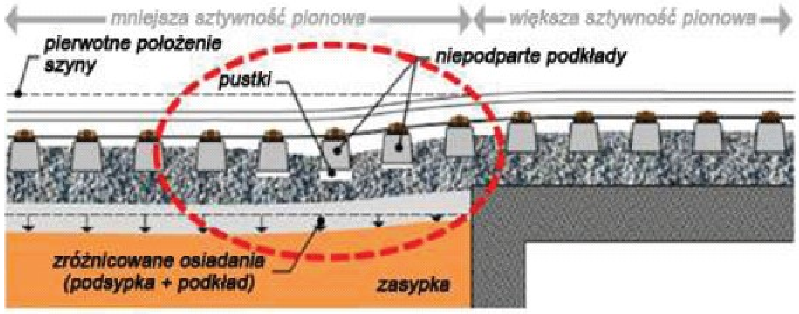
Selected adverse phenomena occurring in the railway surface during operation

At the length of the railway there are actual sections of railway lines with different construction solutions of the surface and railway subgrade, as well as special buildings, engineering structures and devices intended for railway traffic [7, 8, 21]. The result of the changing structure of the railway surface along the length of the railway line is the unfavorable disruption of the homogeneity of the ground, leading to a change in the way the contactless track interacts with this ground and the possible creation of, e.g. threshold effect, i.e. a collection of undesirable and unfavorable phenomena occurring in the railway surface [12, 15, 16]. The scheme of the heterogeneity of the railway construction (at the interface between the track and engineering object) is shown in Figure 2.



2. A typical change in the support of the railway track along the length of the railway [21]

At the interface between the track located on the ground surface and e.g. on the bridge object, there is a significant change in the stiffness of the support - the threshold effect (Fig. 3).



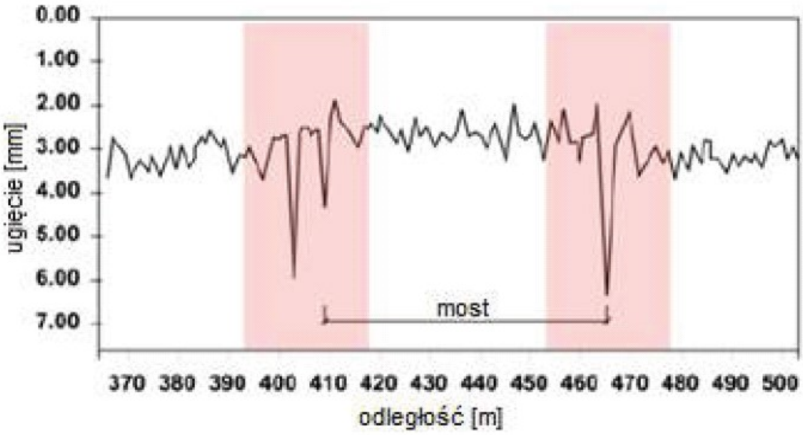
3. Schematic track profile - bridge object [21]

It is defined as a set of unfavorable phenomena in the form of excessive deformations and dynamic interactions, occurring in the places of joining different types of surface, or when connecting surfaces laid on different substrates, eg substructure - engineering object [12, 15, 16].

Threshold effect resulting from the variable path support

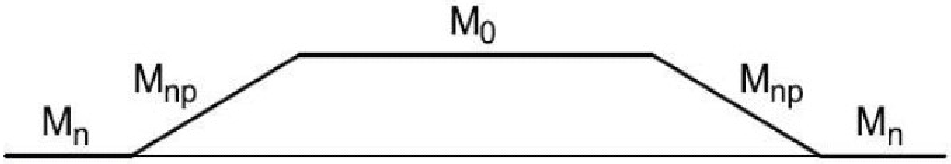
A large number of existing construction solutions of transition zones, minimizing the undesirable effects of the occurrence of numerous structural inhomogeneities and changing ground conditions, results directly from their specific character and the lack of adoption of uniform construction standards. Individual countries have their preferred solutions that are improved over time. All phenomena occurring during the operation of the railway track, which may affect the safety of passengers and traffic, should be diagnosed and controlled [4, 9]. Performing tests of vehicle vibrations during passing through threshold inequalities, controlling the derailment coefficient and periodic repairs affect not only the increase of safety but most of all the comfort of passengers.

The reason for the increased subsidence recorded (Figure 4) is not only the construction of the railway itself beyond the engineering facilities (depending on the geotechnical parameters of the ground or drainage) but also additional dynamic loads from vehicles traveling at higher speeds.



4. Rail deflection profile on the bridge structure and adjacent sections under load [21]

The resulting deformations are not only the result of the changing structure of the railway. The intensity of the threshold effect on approaching an engineering object depends also on many factors, for example on the type of object (bridge, culvert, tunnel), its dimensions and construction material [15, 16]. The type and condition of the surface on the analyzed object and in the surroundings of the object, in particular, the density of neighboring embankments and the type of ground [16], are also important. Increasing the settlement results also from changing weather conditions (temperature and humidity). The scale of this effect depends, moreover, on the type and technical condition of the rolling stock, the speed at which the movement is carried out, as well as on the direction and manner of driving (braking or accelerating) [16]. With the increase of the speed of vehicles passing through the zone of joining the structure, the zone of unfavorable dynamic effects increases [9]. An important factor is also the quality and accuracy of the construction connection and its proper maintenance. In order to minimize unfavorable phenomena and related increased maintenance costs, it is necessary to use appropriate constructions of transition zones. Taking into account the individual nature of the conditions in which the threshold effect occurs, it is impossible to define one universal construction solution for the implementation of the appropriate combination. All the proposed technological solutions are based mainly on the principle of gradual modification of the stiffness of the raily (Fig. 5) [21].



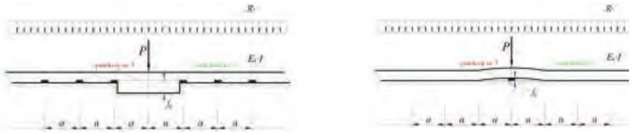
5. An example of a change in the stiffness of the railway line foundation in the embankment - bridge recommended the course of stiffness changes: M_n - modulus of rigidity of the track base in the embankment, M_{np} - modulus of linear stiffness, M_0 - module of the stiffness of the track foundation on the bridge

Analysis of induced imperfections caused in the tracke

In order to analyze the work of loaded track elements on the intended and forced local inequality, field tests were carried out (at the Poznań-Franowo railway station) [6]. The aim of the research was to induce and analyze the intended deformation in the railway track by simulating inequalities in the support of the track in the following two forms:- the reduction of one cross-section in the tested railway track,- raising one cross-section in the tested railway track.
The following measurement diagrams were adopted - Fig. 6:

a) reduction of the cross section no. 2 in the railway track

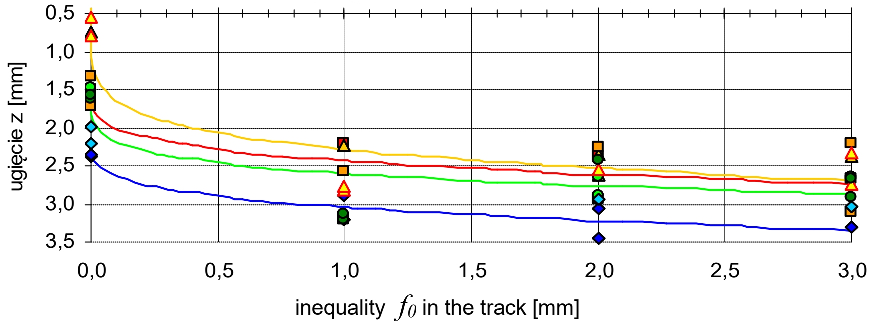
b) increase of the cross section No.2 in the railway track



6. Schemes of unevennesses in the railway track [6]
where: f_0 – inequality caused in the railway track [mm]; P – applied force [MN];
$E_S{\cdot}I$ – stiffness of the track in the vertical plane [MNm^2]; g_t – track weight [MN/m]; a – spacing of sleepers [m].

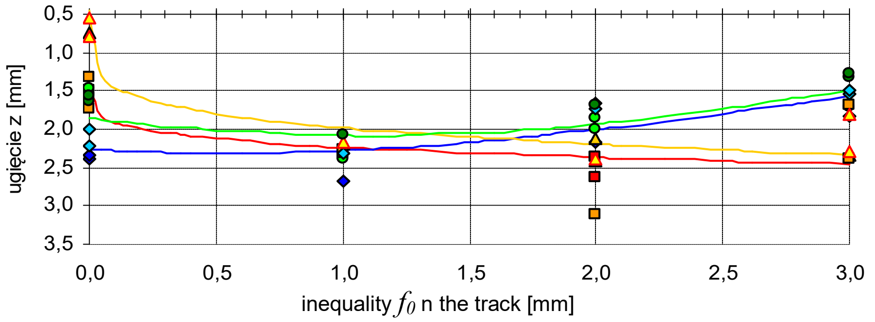
Intentional local deformation was induced in the track by lowering and raising the track by a certain value (parameter f_0 in Fig. 6). The track deformation was obtained by unscrewing the fastenings, lifting the track with a lift (without disturbing the stability of the contactless track in the horizontal plane, in accordance with the applicable regulations), and then placing the metal plates between the rail and the washer, lowering the rail to the washer and re-attaching the rails to the sleepers.
Interesting cognitive insights are provided by the analysis of received rail and base deflection diagrams in the considered cross-section No. 2 (Figure 7). And so for diagram a) from figure 6 received the results presented in the figure 7a and for scheme b) from Fig. 6 the results presented in the figure 7b:

a) reduction of the cross-section No. 2 (diagram from Fig. 6a) - axle pressure no. 2 in cross-section No. 2



- rail deflection in cross-section No. *1*: $z_1^{sz}(f_0) = 1{,}0323 \cdot (f_0)^{0{,}2319} + 1{,}4024$,
- rail deflection in cross-section No. *2*: $z_2^{sz}(f_0) = 0{,}8888 \cdot (f_0)^{0{,}2669} + 2{,}1549$,
- foundation deflection in cross-section No. *1*: $z_1^{pod}(f_0) = 1{,}9002 \cdot (f_0)^{0{,}1771} + 0{,}3868$,
- foundation deflection in cross-section No. *2*: $z_2^{pod}(f_0) = 1{,}1621 \cdot (f_0)^{0{,}1925} + 1{,}4373$.

b) increasing the cross-section No. 2 (diagram from Fig. 6b) - axle load No. 2 in cross-section No. 2



- rail deflection in cross-section No. *1*: $z_1^{sz}(f_0) = 0{,}8104 \cdot (f_0)^{0{,}2201} + 1{,}4239$,
- rail deflection in cross-section No. *2*: $z_2^{pod}(f_0) = e^{0{,}81939 + 0{,}07137 \cdot f_0 - 0{,}06591 \cdot (f_0)^2}$,
- foundation deflection in cross-section No. *1*: $z_1^{pod}(f_0) = 1{,}5453 \cdot (f_0)^{0{,}1857} + 0{,}4396$,
- foundation deflection in cross-section No. *2*: $z_2^{pod}(f_0) = e^{0{,}61767 + 0{,}21025 \cdot f_0 - 0{,}09416 \cdot (f_0)^2}$.

7. Deflection of rail and sleeper due to unevenness in the railway track (pressure of 90 kN / circle); rail 49E1; U=22,836 [MPa]; a=0,6 [m]

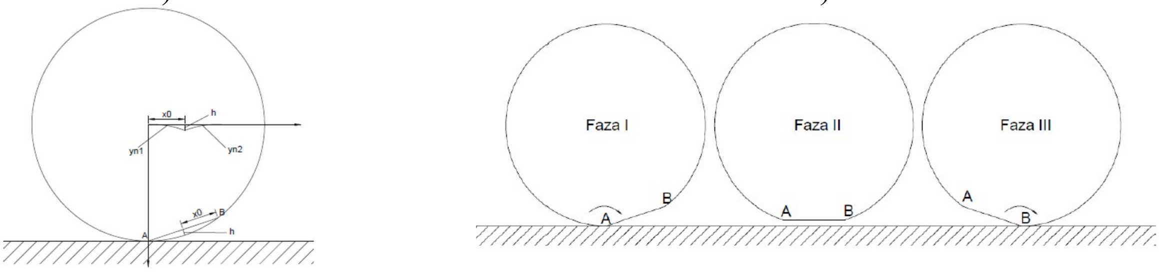
As you can see in the drawings, unevenness f0 arrows triggered in the track significantly change the work of the loaded elements of the railway surface. Particularly in the cross-section no. 2 in question, one can observe a large impact of these inequalities on the work of the railway track. We receive it accordingly [6]:

- for the diagram in Fig. 6a, if there is no deformation in the path (f_0 = 0 [mm]), the sag of the rail is about 2 [mm] (exact value 1.996 [mm]). However, at f_0 = 3 [mm], the rail deflection increases to 3.537 [mm], or 77.2%, and the base deflection increases from 1.437 [mm] to 2.873 [mm], that is by as much as 99.89%. Increasing the deflection of the rail and foundation can be clearly seen in Fig. 6a.
- for the diagram in Fig. 6b, we observe a decrease in the rail deflection under the axis 2 of the locomotive from 2,269 [mm] to 1,553 [mm] depending on the amount induced in the deformation path f_0. The reduction of rail deflection in this case is 31.55% (in relation to the track without preliminary inequalities). The base deflection also decreases from 1.864 [mm] to 1.481 [mm], i.e. by 20.56% (in relation to the track without preliminary irregularities). The reduction in the deflection of the rail and foundation is clearly visible in Fig. 6b. The described changes in deflection lead to an appropriate change in the stress in the rail.

The influence of a flat place on the wheel for additional rail deflections

The movement of the wheel with a flat place can take place without detaching the surface of the rim from the rails or detaching it [11, 13, 19, 20].

a) b)



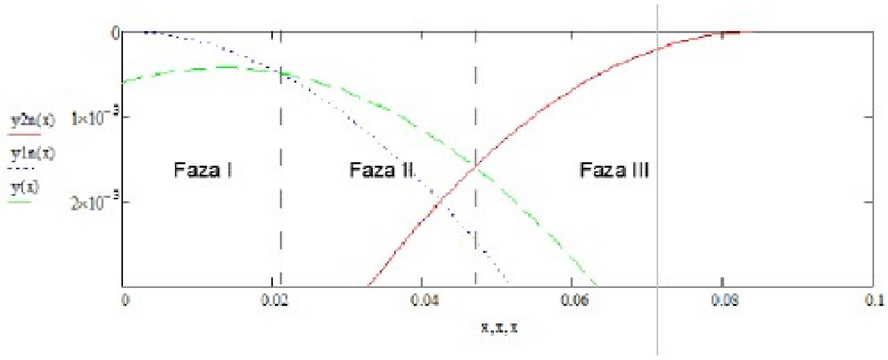
8. Flat place on the wheel [13,19]

a) diagram of a circle with a flat place; b) wheel movement with a flat place - a case of detachment from the rail

The second case occurs when the critical speed wagon passes through the wagon. Due to the given phenomenon, the motion of the center of gravity of the wheel can be divided into three phases (Figure 8) [18]:

- phase I - lasts from the moment when the edge A of a flat place becomes the center of momentary rotation of the circle until the moment the wheel detaches itself from the rail;
- phase II - it lasts from the time when the wheel ruptures to its impact on the rail;
- phase III - last from the moment of impact on the rail edge B to the beginning of rolling the wheel outside the space of the flat plane.

An exemplary graph of the center of gravity movement in all phases is shown in the graph (Figure 9) [13]:



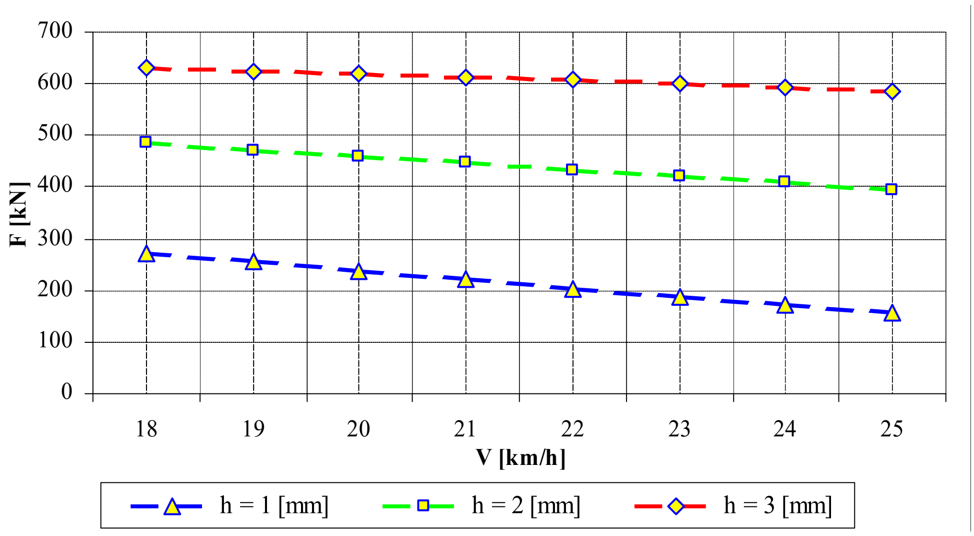
9. Wheel center of gravity motion curves [13]

In case of exceeding the critical speed [13], the trajectory of movement in the second phase takes place after a green dotted line. As the train speed increases above the critical speed, the moment of detachment of the wheel from the rail takes place earlier, while the impact on the railhead afterward. If the speed does not exceed the critical speed, the movement takes place only after the red and blue curves.

Additional force resulting from a flat place on the wheel

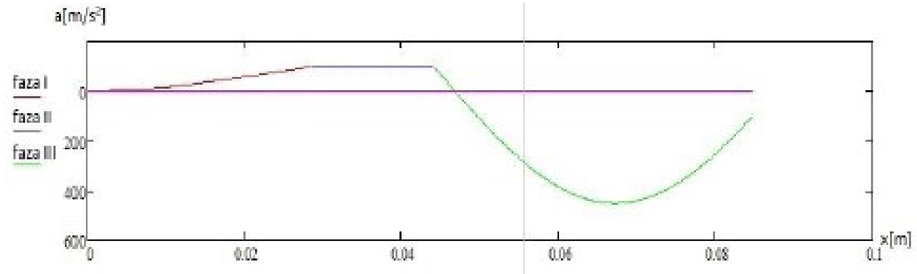
In the case of a flat location on the wheel, the most unfavorable speed of the train, which causes the greatest acceleration of acceleration, is the speed not exceeding the value of V = 25 [km / h] [13]. For the calculations, flat places with depth h = 1, 2 and 3 [mm] were assumed (Fig. 8a). The substrate compliance coefficient was equal to 96.5 [MN / m3], static load per axis equal to 100 [kN], non-sprung weight equal to 10 [kN], and wheel diameter 0.9 [m] [13].

Fig. 10 presents the values of force resulting from a flat place on the wheel for different speeds.



10. The value of the additional force F depending on the depth of the flat place on the wheel and the speed of the train [13]

The strength achieves the highest value when the critical speed is exceeded, followed by a gradual decrease in the force value (mainly due to the decreasing length of the ascending part of the inequality traveled by the wheel) [13]. An example of the course of acceleration changes is shown in Figure 11 [13]:

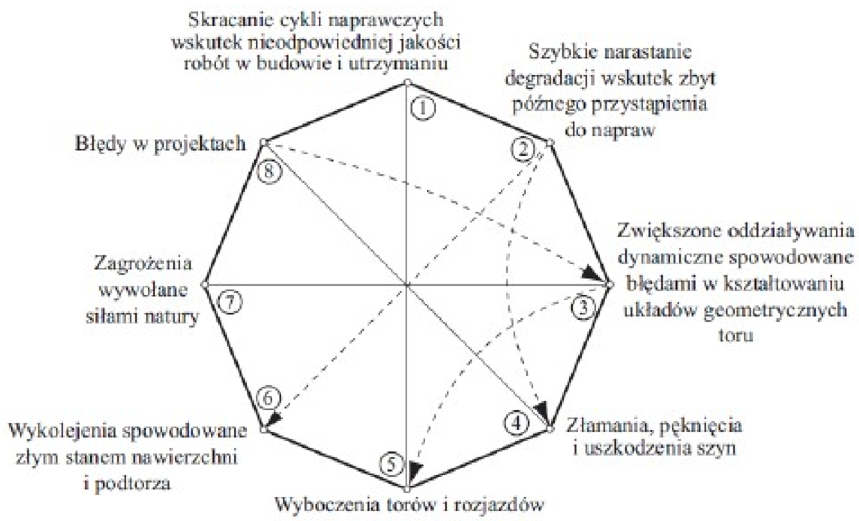


11. The course of the acceleration change for h = 2 [mm] and V=20 [km/h] [13]

The resulting additional force F in a natural way causes additional deflection of the rail (resulting from the existence of a flat place on the wheel).

Undesirable effects of emerging imperfections in the ground and exploitable railway track

Under the influence of railway line exploitation, imperfections are created that have a negative impact on the work of the railway track. Some of them are the result of human error, others are independent of man, and still, others result from the course of the railway line (Figure 11). The division of causes and effects of imperfection in the railway track is presented in Fig. 12 [2]:



12. The basic division of causes and effects of the creation of imperfection in the railway track [2]

Figure 12 clearly shows the causal sequence (in the order of an unfavorable factor-unfavorable phenomenon) causing progressive degradation of the railway surface and reducing its durability and reliability.

In addition, one should remember about other defects or imperfections, accelerating the degradation of the railway surface and diminishing its durability [14]:

– occluded dehydration or lack thereof (Figure 13);
– damaged filter layer or lack thereof;
– landslides;
– settlement of embankments;
– insufficient bearing capacity of the track bed in relation to the permissible speeds and loads;
– progressive degradation of ballast and subgrade;
– failure to comply with the requirements and standards set in standards, instructions and regulations [3];
– mining damage.

13. Trash in the railway track [21]

Conclusions

Based on the analysis, it can be concluded that:

1. The work presents a typical division of imperfections arising in a contactless railway track (after analyzing the literature and the author's own experience).
2. It was found that induced deformations with an uneven arrow f0 in the track change the work of the loaded elements of the railway surface in a significant way (Figure 2.6). A similar form of deformation in the track (vertical irregularities) arises during its operation.
3. The proposed method of inducing deformations is a non-destructive method and does not damage the initial contact between the rail and the substrate with the substrate. The presented method is particularly useful in researching changes in track support and may be an appropriate tool to assess the work of loaded railway track components.
4. Flat areas on the wheel cause a very serious increase in loads at low vehicle speeds. The analysis shows that the most important impact on the amount of additional vertical force is the depth of the flat place, the speed of the train and the parameters of the ground. In addition, it was found that unspringed weight does not have a major impact on the magnitude of the loads (only at the speed at which they occur).
5. The issues examined in the work, the obtained results of theoretical analyzes and experimental measurements, have a practical aspect describing the work of elements of the contactless railway track in the vertical plane with the occurrence of operational inequalities of the track and works related to the maintenance of the track.
6. The work presents examples of unfavorable effects of emerging imperfections or undesirable phenomena occurring in the railway track (shown in Figures 1.1 and 3.1).

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