ANNALS OF FACULTY ENGINEERING HUNEDOARA
– International Journal of Engineering
Tome XI (Year 2013) – FASCICULE 3 (ISSN 1584 – 2673)

[1.] Dana-Mirela COSTEA, [2.] Mugurel-Nicolae GĂMAN, [3.] George DUMITRU

# DYNAMIC CONTACT PHENOMENONS – WEAR OF THE RAILWAY TRACK AND CONSIDERATIONS THE RECTIFICATION OF RAILS

[1.] UPB, ROMANIAN RAILWAY AUTHORITY – AFER, ROMANIA
[2-3.] ROMANIAN RAILWAY AUTHORITY – AFER, ROMANIA

*ABSTRACT: The rectification the running surface of the rail means to remove defects from the surface of the track about the longitudinal profile and the transverse profile of the wheel - rail. From the perspective of the longitudinal profile, high-speed movement of train dynamic forces can be caused by any defect, however small, existing railhead longitudinal profile, multiply substantially static, so a perfect surface without irregularities, it is imperative to obtain. Flank wear surface sinusoidal noise causes an increase in the train running. The high-speed trains, and even irregularities of 0.03 mm depth can create discomfort for travelers and even residents of proximity line. Flank wear surface wave not only causes an increase in noise, but also structural vibration path generally at risk of overloading the track infrastructure.*
*KEYWORDS: lubrication, alloy steel bainitic, sanding, flaking, shock attack forces*

## INTRODUCTION

*The smooth guidance the wheelsets safely to their movement and maintaining stable curve through rails, requires a low tolerance for contact geometry at the railhead. Thus, maintaining adequate rates fungus tread track by stripping them, is a matter of great importance especially for high-speed lines. Specific installation requires high-speed lines and curves that there is little ray which could cause shock attack path. However, the wear wave (approximated as one wave) of the flank surfaces, the rails may occur particularly when high rigidity of the tread. Consequently, heavy concrete sleepers buried in a compact ballast, increase the possibility of notching the rail.*

## WEAR AND TREAD DEFECTS IN RAILS

*At the transverse profile, in terms of the interaction between the wheel and the rail, it is important to retain a second number of important aspects such as the transfer of large forces in a small area but also the stability of the guide wheel. Whether railhead geometry does not match the tread of the wheel contact deformations may exceed the limits of wear material. Sooner or later, this leads to surface cracks on rail fungus known as "cracks in the fungus itself".*

*Even the railways new track surface condition is not always perfect. Tolerance (as rail fastenings etc.) may become negative. Modern rail types, especially the high strength steel, have a very low wear rate close to zero. Consequently, their shape does not adapt quickly to the ideal profile. However, the initial surface rectification of these rails running after installation, is a practice used to be optimum conditions for the wheel – rail from the start. At the same time, the imperfections of the longitudinal profile, such as deficiencies caused by construction activities, printing ballast stones from around the welding irregularities can be corrected.*

*In the a tight, the upper surface of the track rail is exposed to fatigue cracks in the appearance of very fine surface cracks in the mushroom rail so called because of the wheel - rail contact a relatively small area, close to the share A10. To delay the fatigue by surface of the rail profile is required to adequately track surface, moving the contact wheel - rail side (natural wear later will return to the sensitive area). The profile of the rail so-called anti-fracture has been shown to be beneficial, because it ensures a relief of the track. Another approach is to allow only negative tolerance linked to desired standard profile to avoid wheel - rail contact force on a surface footprint limit next listing A10. High speed trains are more sensitive to any irregularities lateral control parameter being equivalent taper conicality. Influences track on this parameter are given by: Profile rail, rail inclination and track width. The train speed is higher, the equivalent taper is smaller, so that the lateral oscillations are reduced. For speeds of 200 km / h, the amount thereof should be about 0.1 and must not exceed 0.3. No taper conicity value below 0.5 is acceptable, whereas it diminishes the ability guidance the wheelsets, which can cause shock attack.*

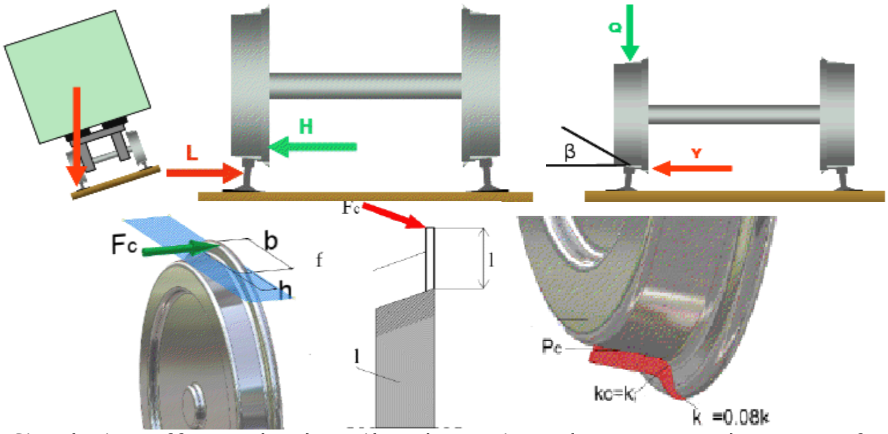


*Figure. 1. Simulation efforts wheel - rail and reactions that occur and cause surface damage*

*In order to ensure the smooth guidance the wheelsets on rails, the track must be kept relatively constant. Thus, lateral oscillations are reduced and unstable driving conditions mentioned frequently hunting movements do not occur. Where the track width is insufficient, this can be corrected by adjustment of track width profile. The stability of the lateral movement could be improved by the application of rail profiles of high convexity which provides a low equivalent conicity. Apart from geometrical irregularities, the fungus itself may suffer structural changes. Over the period of operation of the rail, damage and tread wear fatigue progresses, requiring interventions. The damage the running surface in some high speed lines is due to the cracks in the tread depth. Movement of high speed trains produces air turbulence around and under cars so ballast stones from the bed can be raised. Whether they fall on the rail in front of the wheels, they are crushed and leave traces of surface rail bed ballast stones of various depths. Most susceptible to this phenomenon are the areas around the passages and cuttings. In winter, the printing surface may be due to ice rail falling off cars when they approach the warmer areas. Printing surface itself acts as a sinusoidal surface flank wear, causing dynamic forces and vibrations at high levels. Usually they print the rail surface to 0.3 mm depth, and some reach 0.5 mm deep. In order to avoid negative consequences, print track surface are removed by correcting the annual campaign to a tread depth of 0.3 mm. In this way, most printing is eliminated and those that remain are reduced to an acceptable depth, until they are removed at the next rectification campaigne. Fatigue wear can occur to the rail surface in the form of cracks in the fungus itself, as explained above, when it is made of rail steel is subjected to high dynamic forces, or when the contact wheel - rail, the area itself is small, the fatigue limit of wear is reached. Under these conditions, the fatigue wear of tread fungus appears as cracks in the rail, especially high speed lines, the curves. Whether not tampered with, the cracks can sometimes increase in the upper part, leading to flaking and milling, and sometimes in the lower, resulting in possible breaking of the rail.*

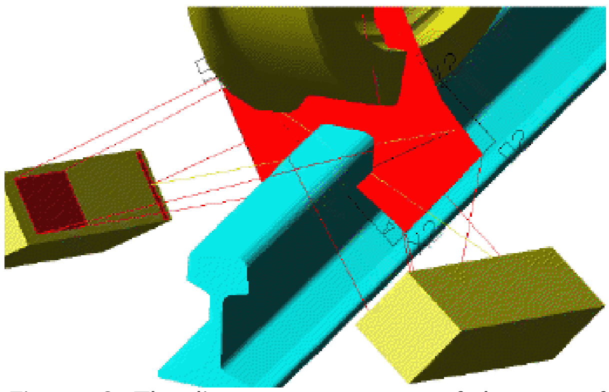

*Figure. 2. The direct measurement of the area of wheel - rail contact ultrasonic reflection method*

*The timely removal of these cracks by grinding tread keeps worsening cracks under control. It is essential that action to occur at the appropriate time because the degree of crack growth increases over time and crack spread can vary considerably. The cycles of grinding the rolling surface of a metal removal rate of up to 0.5 mm are desirable as they balance the delivery of fatigue and wear.*

*An adequately anti fissure rail profile helps reduce fatigue and initial therefore aggravation wear. Holes or black spots on the rails, the contact wheel - rail is more or less in the center railhead. Sometimes isolated surface cracks extending near and parallel to the track surface and become so called blackheads. Occasionally these deep cracks can, causing in the end, the rail break. When the rails are rectified at fixed intervals, these defects are removed at an early stage so that they do not cause catastrophic damage. Itself affected by sinusoidal surface flank wear was observed another phenomenon of fatigue wear. On the surface there is a rail network of cracks, a kind of mushroom mixture on track irregular cracks and small holes that have a high risk of further severe damage. In the contact area between wheel and rail are normal and tangential transmitted load (Figure 1). In that situation, it was examined how touching steel wheel and steel rail as the size of the forces transmitted in the contact area is influenced by degradation and surface wear and tear. When the two surfaces in contact, which occurs as a task, they move one on the other, occurring wear. Wear is* *defined usually as a breakdown of one or both surfaces, which involves loss of material. The friction force could be defined as the resistance encountered by that moving body on the surface of another body. This definition applies to both bodies slipping and those that roll. It should be noted that even pure rolling almost always involve some slip, and the two types of motion are not mutually exclusive. Any substance of the contact surfaces could thus affect the frictional force. Contact conditions can quickly disperse substance and its effects will be minimal. On the other hand, the film formed on the surfaces interposed between the substances has a major effect on the behavior of friction. Considerations friction in terms of wheel - rail contact and causes loss of traction and ways to enhance it, to reduce wear and degradation caused by contact fatigue tread etc., consist of a lubricant in the wheel - rail contact. In the contact area between wheel and rail station, areas and raw material should be strong enough to withstand normal forces (vertical) carried heavy loads and dynamic response induced by rail and wheel irregularities. The tangential forces in the contact area should be sufficiently low to allow movement of the dynamic overload of low resistance. Meanwhile, tangential tasks must be large enough to allow towing, braking and handling of trains. Contact area (about 1 cm$^2$) of a train wheel and the rail is small compared to their total size and shape depends not only on the geometry of the rail and the wheel, but also how the wheel touches the track, or lateral position and the angle of the front wheel track.*

*The direct measurement of the area of contact between the wheel and the track is difficult. Such reflection ultrasound technique was used (Figure 2) and the results were compared with the calculated contact areas, demonstrating a good agreement between themselves.*

*The size and shape of the wheel touches the contact rail can be calculated by various techniques. Traditionally, the elliptical Hertz contact theory was used, with the following assumptions: the buttons are soft and can be described by the surface of the second order, the model material has no linear elastic friction between the contact surfaces, come in contact bodies is assumed to deform the limit, to infinity, in the semi-contact surfaces. Alleged superposition of semi contact surface, impose limits on the contact geometry, that means a significant amount of contact area must be small compared to the radii of curvature relative to each body. Due to its simple solutions, Hertz is the method used to simulate the vehicle dynamics. However, for simulation of wear and surface fatigue using other methods of contact deformations due to overvaluation semi-surface of contact assigned invalid and non-linear material behavior. Contact the numerical software developed by Kalker, still relies on semi-surface but not reduced to elliptical contact areas. It was developed a finite element model of wheel - rail contact, including plastic deformation, using as input "input" measurements of rail and wheel profiles (Figure 3). Were also compared to traditional methods (Hertz and Kalker) with detailed solutions based on the finite element contact with the side of the rail wheel. The results of the two experiments show that the maximum contact pressure difference between the methods Hertz / Kalker and their design was low when the minimum radius of contact is large as compared with the material dimensions of the contact surface (semi-surface of contact assumptions were found to be valid). However, the minimum radius of contact was not significantly lower compared to the size of the surface, the difference between the model and methods Hertz / Kalker was high, reaching to 3 GPa.*

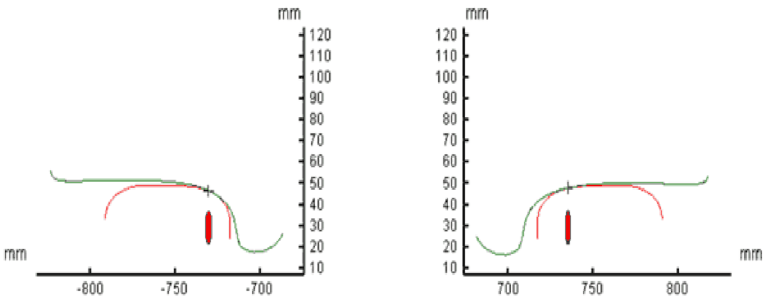


*Figure. 3. The wear and tear the wheel - rail contact leading to damage the contact surfaces*

*In the case of the contact between the rail and the road surface fungus of the wheel slip speed and the contact pressure did never exceeded 0.1 m / s and, respectively, 1.5 GPa. In the contrast, when contact between side rail and the wheel rim, the maximum slip velocities reached 0.9 m / sec, and maximum contact pressure was above 2.7 GPa. This is a sharp curve, in one of the smallest radius of the entire network, where we can observe a very high contact pressure on the first wheel to make contact with the rail bogie. Changing profile of the wheel could be significant, especially on a taxiway located in the curve. The mechanical deformation such as wear and plastic deformation, the greater contribution to changing the profile. Another problem becoming more serious for one network is due to rolling contact fatigue. Wear is the loss or displacement of the material on the contact surface. Loss of material can be in the form of chips. Deployment of the material can take place through the material transfer from one surface to the other by welding or local deformation. Another type of wear that results in smooth oxidation aging process is characterized by displacement of the oxide layer on the surface of contact. Into this case, the contact temperature and the roughness affects the extent of wear. Abrasive wear caused by hard particles, located between the contact surfaces, causing significant wear and reduce the life cycle of contact (Figure 4).*

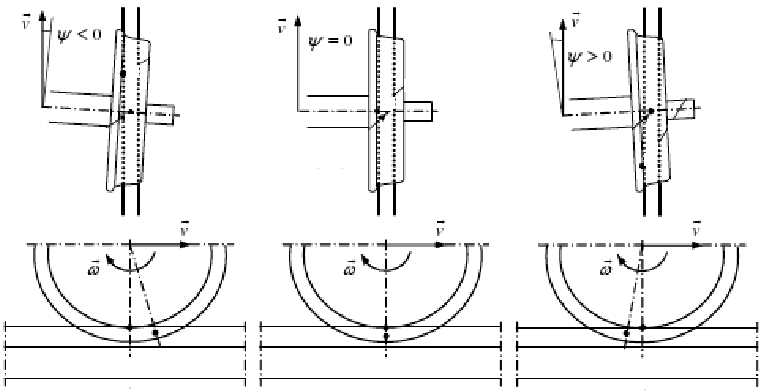


*Figure 4. Measuring wear contact surfaces wheel - rail*

*An analysis of the relationship between the weather and wear track shows that rainfall has a significant effect on the degree of wear of rail. The radius of curvature of the path has a strong influence on the wear track. This influence depends on the vehicles and their behavior. Into this case, the influence of the radius of curvature could be easily observed considering the degree of wear of the rail as a function of the radius of curvature. The degree of wear of the guide bar seems to exponentially increase the radii of curvature. For curves un-lubricated, wear rate between the track rail compared to UIC 900A to UIC 1100 is approximately 2. This can be compared with beneficial lubrication factor is approximately 9 to the curve. Perlitic rails are still the most common and is used by most rail networks. Perlite is a lamellar eutectic composition formed in the steel during continuous cooling transformation by isothermic. It is composed of ferrite and cementite. Has been shown now that pearlitic rail wear by reducing the space between tabs inter lamellar Cement produces an increase in hardness. Structural steel bainitic (from austenite transformed) are other types of alloy steel for rails. They have a better fatigue wheel - rail contact than pearlitic. However, the wear resistance of the rail is lower bainitic and pearlitic rails at a constant tear force. Into alignment, the wheel is in contact with the fungus itself, but the curved rim lip may be in contact with the railhead tor flank. The weight of the wheel is transmitted to the rail by means of a small contact area with high contact resistance. This results in a repeated request beyond the elastic limit leading to a plastic deformation.*

*At the wheel - rail, both rolling and sliding occur in the contact area. Especially in curves, there may be a component of the path of the sliding side to side contact between the rail track and fungus (on the outskirts of gauge). Because of this slippage, wear occurring during contact due to poor lubrication conditions, typical of the wheel - rail. One observation that can be made about wear due to sliding is that increasing the load (normal load, sliding speed or high temperature) leads to a certain level, a sudden change in the degree of wear (loss of volume per distance slip). Severe wear may be associated with seizure / riding. Also as a result of the above, may occur as a result of the wear track the movement of rolling stock to run the operating profiles misusage, obtained during running flats (Figure 5).*

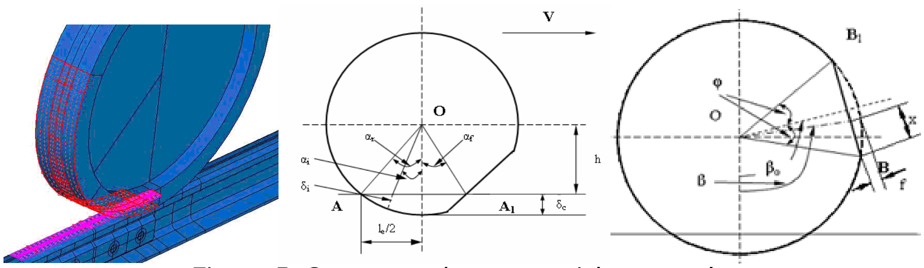


*Figure 5. Spent tread pattern with space plan*

*The depth efforts concentrator device depend on rail hardness and roughness curve, it must not exceed 15 mm. When a material is subjected to repeated request, the response depends on the rate of the amplitude of the maximum resistance to the elastic limit of the material. When the application grows beyond the elastic limit, the contact resistance exceeds the elastic limit and the material becomes permanent deformation. After the wheel has passed the residual strength developers. The residual resistance is designed to protect their nature, in that they reduce the tendency for plastic deformation of the rails (Figure 6) for subsequent passes of the wheel. These and any effect of natural resistance of rail steel material make it possible to withstand pressures are much higher than its elastic limits. This process is called elastic adjustment and minimize the contact resistance in this process it is possible to adapt is known as the elastic limit. There is also a fine adjustment limit. Requests between the elastic limit and the limit of adaptation plastic cyclic plasticity will lead to rail. If repeated cyclic plastic deformation occurs and the material itself can reinforce cyclical, leading to an increase in the limit of elasticity and deformation tendency is reduced. Contact cracks due to fatigue due to the operation can be classified into those which start below the running surface and the surface. The under surface are often caused by metallurgical defects. On the other hand, the surface appears to be the result of heavy traffic and load on the axle. A more accurate classification can be made: scrub, scratch and points oval holes. Exfoliation is a sub-surface defect appearing on the curved flank tor when the axle load is high. An elliptical crack propagates as a clam mostly parallel to* *the surface. In many cases, metal flakes off the flank tor. When the crack length reaches a critical value, it may extend the rail, causing the rail breaks.*

*Other mechanisms of formation of holes are related to longitudinal traction wheel that makes the surface layer of the material to plastic is increased until a crack appears on the mushroom rail. Due to contact fatigue cracks due to rolling of the wheels can be classified as scrub and flaking. The exfoliation is a defect due to rolling contact fatigue under surface, which appears on the nominal rolling circle of the wheel, and the mechanism is similar to the occurrence of flaking on track. The flaking may appear on the surface nominal rolling circle when powerful slide rail wheel braking. The surface temperature of the wheel above the austenite amounting to the value of 720°C, to form the martensite, a hard, brittle shaped steel. This form will collapse slightly during the following passages wheels turning in flaking. Has been shown by laboratory tests that the thermal treatment of the fungus reduced rate rail scratches and field trials are under implementation to determine if this behavior is the same in real situations.*

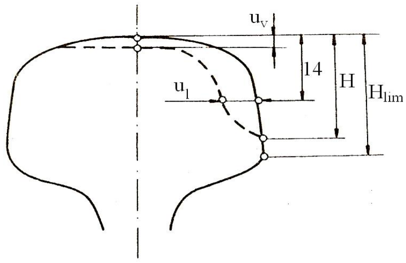


*Figure 6. Highlighting the plastic deformation of the rail tracks*

*The friction force could be defined as the resistance of a body motion occurring over a different body. This definition applies to both bodies and the gliding running. It is noteworthy that almost always involves pure rolling and sliding and that the two kinds of motion are not mutually exclusive. Resistance force which is parallel to the direction of movement is called the frictional force. If the two solids are required, static friction is equal to the tangential force necessary to start sliding between bodies. Kinetic friction tangential force required to maintain sliding. The kinetic friction is generally smaller than the static friction. For bodies that slip friction and thus the friction coefficient is, force relative to the normal force. They depend on three different mechanisms, under no lubrication and mixed lubrication or asperities forming, joining and pulling the sliding surfaces of particles caused great damage and roughness. For the most of metals, the maximum value of the coefficient of friction is between 0.3 is 1.0. Pull-out component of the coefficient ranges from 0 to 1.0 and the joining component ranges from 0.0 to 0,4 were found. It is recognized that due to the rolling friction surface is considerably less than the un-lubricated sliding friction dried in the same area. To contact the steel wheel to steel rail rolling friction coefficient is of the order of 1 x 10-4. The area of contact between the wheel and the rail could be divided into rolling and sliding surface. The lateral deflection and the tangential forces (traction) increase due to the slippage that occurs in the rear region of the contact surface. On increasing tensile force, the region of slip increases and decreases running region, resulting in a rolling and sliding contact. When the tensile forces reach saturation value, the road surface disappears and the whole contact area is in a state of pure slip. The maximum thrust achieved depends on the contact surface to absorb traction. This is expressed as the coefficient of friction, which is the ratio of the tensile force and the normal load N normally thrust on the wheel rim reaches its maximum value at the limit of adhesion of the 0.02 to 1.01.*

*The curve traction / adherence could be deeply affected by the presence of a third intermediate layer occurred in the wheel - rail. It can be made of a substance made to increase / decrease friction (lubricant or friction modifier) or naturally by a substance that reduces friction that water and leaves. In many researches, which are found in the literature, there are proposals for a model of rolling friction sliding contact, separating them by an interstitial layer, based on three rheological parameters: plasticity modulus G and k and critical pressure uniformly distributed $\tau_c$. It was proved that friction is strongly affected by three factors rheological, sliding distance and workload evenly distributed relative to the sliding distance representing the dominant influence.*

*The friction between the wheels and the rails is very important because it plays a major role in the interface wheel - rail, such as joining, wear, contact fatigue due to the operation and production of noise. Effective control of friction by applying friction modifiers wheel - rail contact is so very great, even if the process must be carefully conducted. Friction management goal is to maintain levels of friction at the wheel - rail for low friction at the contact between the tire and rim flank tor, intermediate frictional contact between nominal rolling circle of the wheel and rail fungus, especially for freight vehicles and not least for high friction at the contact between nominal rolling circle wheel and rail locomotives fungus, especially where problems of loss of adhesion. Also when conducting successive experiments were comparable friction coefficients measured in laboratory and field conditions. In the case of pure sliding test without lubrication, the level is about the same, varying between 0.5 and 0.6. For the rail lubrication friction coefficient was lower and ranged between 0.2 and 0.4.*

*The absence of adhesion to means a safety problem braking, because it results in greater stopping distance. Research adherence problems encountered in high-speed lines, using both sliding-scale mechanisms in the laboratory and in field measurements showed that adherence decreases with* *speed and strength train wheel - rail contact. The experimental results indicated that the greatest influence on the adhesion of the wheel and had a surface roughness of the surface tension (adhesion increases with increasing roughness). The main factor used to enhance adhesion international railway networks is sand.*

*The sanding is used for operations for improving the adhesion of both the rail and the wheel brake. For the stop the train braking is customary to ensure a distance as short as possible. This triggers usually automatically when the driver chooses braking. Sanding in the wheel is a manual process, however. The driver must determine when to throw sand and how long to take this operation. Drivers may be tempted to throw sand to compensate and increase friction, and this action in turn will lead to increased wear and cause blockage applicators.*

## CONCLUSIONS

*On the high-speed lines, points of stability for track maintenance machines are located at a great distance, and work is possible during the night. To keep track efficiency in these conditions, some railway network path using heavy machinery to rectify the track in a step. For the removal of more than 0.2 to 0.3 mm metal grinding machines can be connected together to perform work on large areas with a very high working speed. Thus, approximately 25 km of track can be adjusted during an exchange. The rectification tread the switches involve a series of works on the rails, which are sensitive to damage to the track surface. Running on rails counter switch blades and over crossings involving large dynamic forces and lateral movements. On the high-speed lines are frequently observed crossings pits and fissures switch lines. Several railways have started to correct tread on high-speed lines to switches in the same way as normal lines. Maintaining ideal railhead profile and switches is of particular importance. Profiles inclined rails, the rails are mounted vertically standard today. Successfully tested anti fissure rail profiles for switches. On the long switches on high-speed lines can be used special equipment to rectify the switches. During the rectification switches, special attention should be paid to control dust and clean the area to be avoided switch malfunction. The rectification treads integral part of maintaining track on high-speed lines. Today all newly built high-speed lines are rectified before putting into service. Correction programs are executed most often in order to maintain the noise and vibration to an acceptable level, and thus to improve the comfort of the passengers. In some places the tread correction is performed at intervals to remove irregularities from the surface of the rail.*

*Theoretically, at all high-speed lines the phenomenon of fatigue wear, which requires cyclical correction. On the high-speed lines have been successfully introduced antifissure rail profiles and profiles with high convexity.*

## REFERENCES


[1] ADOLFSSON, K. & others, "High speed lines on soft ground. Evaluation and analyses of measurements from the West Coast Line", Technical Report, Banverket, Sweden, 1999.
[2] DUMITRU, G., "Consideraţii privind reducerea efectelor zgomotului produs de circulaţia cu viteze mari a vehiculelor motoare de cale ferată" (Considerations to reduce the effects of traffic noise high speed railway vehicle engines), Revista MID CF, ISSN 1841-1207, pp. 27 – 33, nr. 4 / 2006.
[3] DUMITRU, G. & others: "Characteristics Of Guidance Safety For Locomotives Under Traction And Braking On Circulation In Curve Fitting", in RailwayPRO Science & Technology - Official Magazine For Club Feroviar Conferences & Technical Colloquia, ISSN 2284 - 7057, pp. 53 – 61, April 25 - 26, 2012, Constanţa.
[4] KALKER J. J., "Three dimensional elastic bodies in rolling contact", Kluwer Academic Publishers, Dordrecht, 1990.
[5] MAZILU, T., "Vibraţii" (Vibrations), Editura Matrix Rom, Bucureşti, 2012.
[6] NADAL, M. J., "Locomotives a Vapeur", Collection Encyclopédie Scientifique, Bibliothèque de Mécanique Applique´ et Génie, Paris, 1908.
[7] MATSUDAIRA, T., "Dynamics of High Speed Rolling Stock", Japanese National Railways RTRI Quarterly Reports, Special Issue, 1963.
[8] MATSUOKA, K. et. al: "Development of wheel - mounted direct drive traction motor for rail vehicle", Electric Railways and Transportation Meeting of IEEJ, 1995.
[9] PRUD'HOMME, A., "Les problems que pase, pour la voie, la circulation des rames a grande vitesse", Revue Generale des Chemins de Fer, Nov. 1976.
[10] SCHEFFEL, H., Conceptions Nouvelles relatives aux dispositifs de suspension des véhicules ferroviare, Rail International, dec., 1974.
[11] SEBEŞAN, I., MAZILU, T., Vibraţiile vehiculelor feroviare (Vibrations of the railway vehicles), Editura Matrix Rom, Bucureşti, 2010.
[12] SUNAGA, Y. & others: "Detection of the Short Wave Track Irregularities of High Speed Shinkansen", in RTRI (Railway Technical Research Institute) Report, Vol. 13, No. 5, 1999, pp. 11-16.
[13] TANAKA, T., KINOSHITA, K & NAKAYAMA, H.: "Effect of Loading Time on High Cycle Range Impact Fatigue Strength and Impact Fatigue Crack Growth", in JSME International Journal", Series I, 35 (1), pp. 108 - 116, 1992.
[14] VAN BOMMEL, P., "Consideraions lineaires concernant lemouvement de lacet d'un vehicule ferroviare", UIC / ORE C9, nov., 1968.
[15] WATANABE, T. & YAMASHITA, M., "Basic Study of Anti-Slip Control Without Speed Sensor for Multiple Motor Drive of Electric Railway Vehicles", Proceedings of the Power Conversion Conference, Vol. 3, pp. 1026-1032, 2002.
[16] Journal of Dynamic Sistems: march 2003
[17] Nonlinear Dynamics: no. 13 / 2007
[18] Quarterly of Applied Mathematics: april 2008