

ŠINSKI DEFEKTI USLED ZAMORA MATERIJALA

RAIL DEFECTS DUE TO ROLLING CONTACT FATIGUE

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1 UVOD

Defekti šine usled zamora materijala u zonama velikih kontaktnih napona su izražen fenomen i problem na železnicama širom sveta. Najpre su defekti ovog tipa uočavani samo na šinama u kolosecima pruga za težak teretni saobraćaj sa velikim osovinskim opterećenjima (slika 1). Međutim, danas se ista pojava uočava na konvencionalnim prugama za mešoviti saobraćaj, kao i na prugama za velike brzine, naročito za brzine preko 200 km/h.

Kada se točak teškog teretnog šinskog vozila osloni na šinu, oba tela u tački dodira dobijaju ugib. Formirana dodirna površina točka i šine je izuzetno mala i iznosi svega 1.5 – 3.0 cm² (slika 2). Velika opterećenja od točka prenose se preko male dodirne površine na šinu, što stvara velike napone pritiska. Prekoračenjem granice elastičnosti, šinski čelik se istiskuje ka neopterećenoj okolini dodirne površine, remeti se njegova mikrostruktura i dolazi do plastične deformacije šine.

Sa druge strane, sa porastom brzina na prugama ukupno opterećenje (slika 3) od točka koje deluje na šinu povećava se zbog porasta udela dinamičkog opterećenja. S obzirom na to da upravljač železničke infrastrukture nema uticaj na konstrukciju i stanje vozila, jedan od raspoloživih načina da utiče na smanjenje dinamičkog opterećenja koje se prenosi na šinu je upravljanje održavanjem profila glave šine.

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1 INTRODUCTION

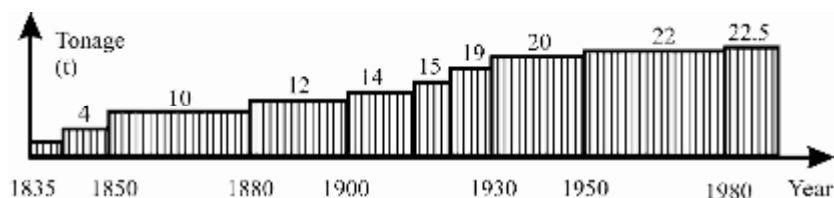
Rail defects due to rolling contact fatigue in the areas of high wheel/rail contact stress is a marked phenomenon and a problem on the railways worldwide. At first, defects of this type have been observed only on the tracks of heavy haul lines with high axle load (figure 1). However, nowadays the same occurrence is discerned on conventional lines for mixed traffic as well as on the high speed lines, especially for the speeds over 200 km/h.

When the wheel of a heavy freight vehicle relies on the rail, both bodies are flexed at the point of contact. Thus formed wheel/rail contact surface is very small and it measures only 1.5 – 3.0 cm² (figure 2). High load is transferred over the small wheel/rail contact surface from the wheel to the rail, which creates high pressure stress. Overflow of the elasticity limit forces the rail steel outwards toward unstressed contact surface environment, its microstructure is perturbed and the rail suffers plastic deformation.

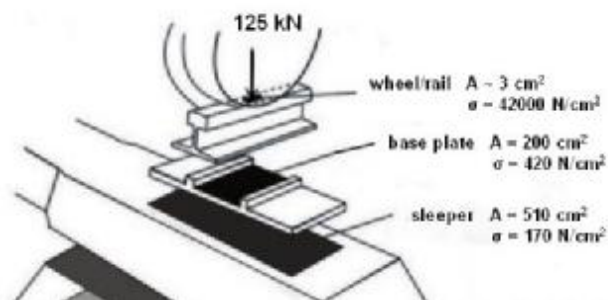
On the other hand, the increase of line speed (figure 3) increases total wheel stress on the rail due to an increase of the dynamic stress rate. Since the infrastructure manager doesn't have influence on the construction and condition of the vehicle, one of the available ways to influence reduction of dynamical stress transferred to the rail is managing rail head profile maintenance.

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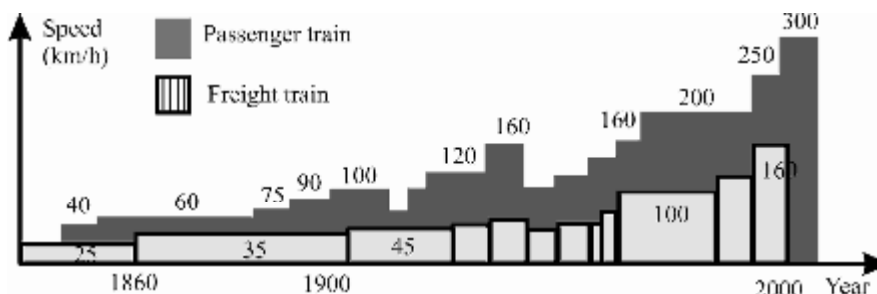
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Slika 1. Porast osovinskog opterećenja [8]
Figure 1. Increase of the axle load [8]



Slika 2. Veliki napon u dodiru točka i šine [7]
Figure 2. High wheel/rail contact stress [7]



Slika 3. Porast brzina [8]
Figure 3. Increase of the speed [8]

2 DEFEKTI USLED ZAMORA ŠINSKOG ČELIKA

Zamor šinskog čelika predstavlja proces postepenog razaranja usled nastanka i razvoja inicijalne prsline, sve do loma šine u koloseku pod dejstvom promenljivog opterećenja od saobraćaja, koje se na šinu prenosi preko male površine dodira sa točkom vozila.

Površina loma usled zamora materijala, u opštem slučaju, ima karakterističan izgled. Na njoj se mogu uočiti dve vizuelno izrazito različite površine: zona zamora i zona nasilnog loma (slika 4).

Zona zamora ima glatku i tamnu površinu u kojoj se uočavaju linije porasta zamorne prsline, a nalazi se na mestima povećane koncentracije napona usled:

- geometrijskog oblika i konstruktivnih karakteristika profila (prelazna zaobljenja poprečnog profila, rupe u vratu i sl.),
- površinskih oštećenja (zarezi od alata za obradu),
- tehnološkog postupka proizvodnje,
- oštećenja u eksploataciji i
- drugih defekata.

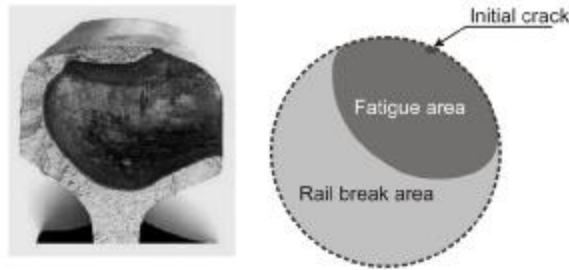
2 DEFECTS DUE TO ROLLING CONTACT FATIGUE

Rolling contact fatigue is a process of gradual destruction due to the creation and development of an initial crack, until the rail breaks under the influence of variable traffic load, which is transferred to the rail via a small wheel/rail contact surface.

Generally, a fracture surface due to rolling contact fatigue has a characteristic figure. Two visually different surfaces can be distinguished: fatigue area and rail break area (figure 4).

Fatigue area has a smooth and dark surface where the lines of fatigue crack increase can be distinguished, and it is on the places of increased stress concentration, due to:

- geometry and constructive characteristics of the profile (transitional roundness of the cross profile, holes in the neck, etc.),
- surface damage (incisions from working tools),
- technological method of production,
- exploitation damage, and
- other defects.



Slika 4. Karakteristični izgled površine materijala nakon loma usled zamora šinskog čelika
Figure 4. Characteristic look of a steel surface after break caused by rolling contact fatigue

Razvoj prsline se može izraziti kao porast njene veličine u odnosu na akumulirano saobraćajno opterećenje (izraženo u milionima bruto tona). Rast prsline zavisi od mnogobrojnih faktora. Najvažniji uticajni faktori za rast prsline su [5]:

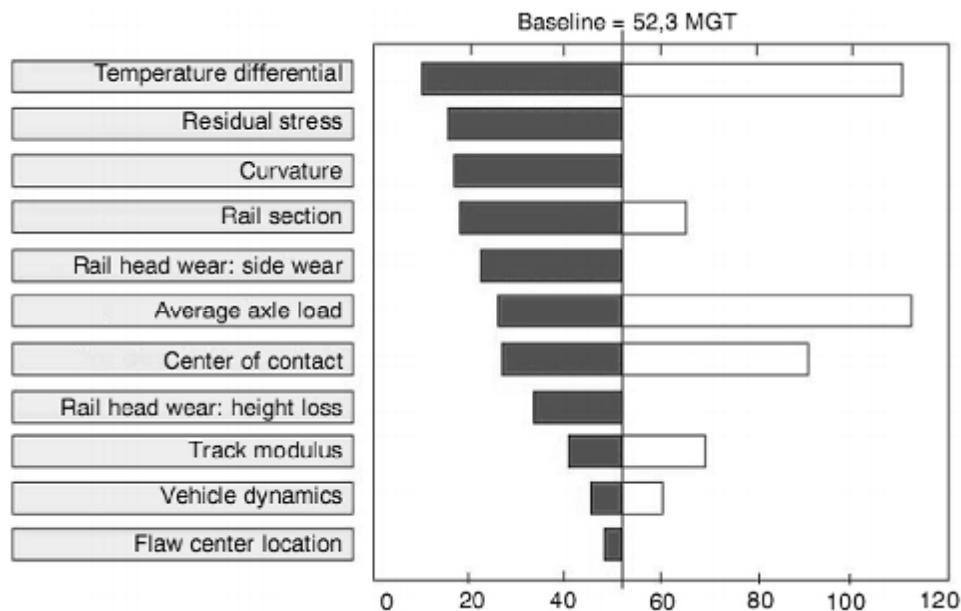
- statičko opterećenje od točka,
- dinamičko opterećenje od točka,
- karakteristike kretanja vozila (vuča, kočenje itd.),
- profil šine,
- kvalitet šinskog čelika,
- vrsta defekta,
- temperaturna razlika (temperatura u šini - neutralna temperatura pri kojoj je šina bez napona),
- sopstveni naponi u šini (zaostali naponi),
- habanje glave šine,
- stanje geometrije koloseka,
- krutost šinske podloge.

U okviru projekta [10] sprovedena je analiza osetljivosti kako bi se predstavio uticaj različitih uslova saobraćaja i konstrukcije gornjeg stroja na rast prsline (videti sliku 5). Slika 5 prikazuje rezultate ove analize. Redosled uticajnih faktora na slici odražava njihov uticaj na napredovanje veličine prsline u toku eksploatacionog veka šine.

Defect crack growth can be expressed as an increase in defect size per accumulated gross ton traffic load (million gross tons – MGT). Crack growth depends on many factors where most important are [5]:

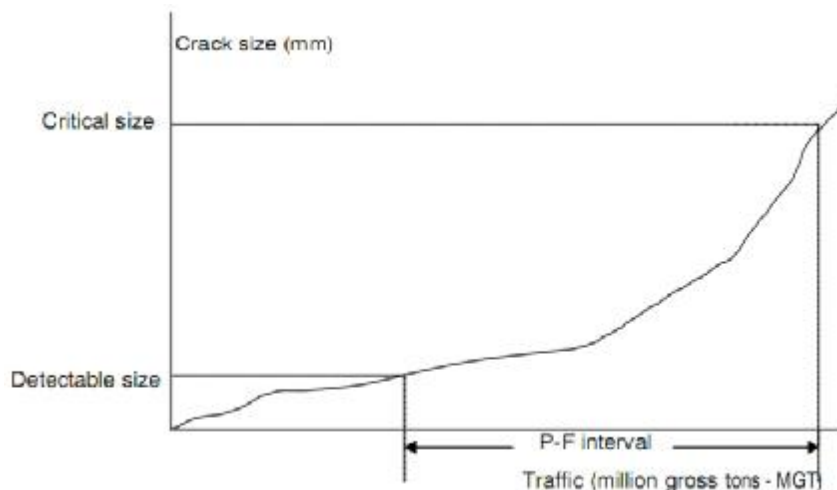
- static wheel load,
- dynamic wheel loads,
- vehicle rolling characteristics (traction, braking, etc.),
- rail profile
- rail steel,
- defect type,
- temperature differential (rail temperature - stress free temperature),
- residual rail stress,
- rail head wear,
- track geometry,
- track stiffness.

As a part of the project [10], a sensitivity analysis was performed to demonstrate how different traffic and track conditions affect crack growth rate (see figure 5). Figure 5 shows the result of the analysis. The various factors are ranked according to the impact the crack growth caused has on rail life span.



Slika 5. Uticaj različitih faktora na rast prsline (P-O interval) [10]
Figure 5. Influence of various factors on crack growth rate (variation of the P-F interval) [10]

Prslina se može pouzdano detektovati tek od njene određene veličine (P - potencijal razvoja prsline pre detekcije). Ova veličina zavisi od metode detekcije i predstavlja početnu veličinu od koje se prslina razvija sve do dostizanja kritične veličine, pri kojoj se može očekivati lom (O - otkaz usled loma). Za definisanje intervala P-O može se koristiti proteklo vreme ili prevezeno saobraćajno opterećenje (izraženo u milionima bruto tona) u vremenskom intervalu između detekcije prsline i loma šine (slika 6).



Slika 6. Definisiranje P-O intervala [10]
Figure 6. Definition of the P-F interval [10]

U zavisnosti od tipa defekta, brzina rasta prsline je veoma različita. Jednostavan matematički model rasta prsline može se izvesti samo za poprečnu prslinu u glavi šine [5].

U ovom radu se predstavlja i analizira pojava karakterističnih defekata šine usled zamora materijala, poznatih pod nazivima: head checking i squat. Ukratko se predstavlja defekt tipa belgrospi, koji je karakterističan za velike brzine. Nazivi head checking, squat i belgrospi se koriste zvanično na svim jezicima sveta u naučnoj i stručnoj literaturi bez prevođenja.

Pomenuti defekti nisu obuhvaćeni Uputstvom 339 o jedinstvenim kriterijumima za kontrolu stanja pruga na mreži JŽ, koje je na Železnicama Srbije još uvek u zvaničnoj upotrebi [11]. Za sada ne postoji naučna literatura na srpskom jeziku koja obuhvata ovu oblast.

Priručnik za šinske defekte (Handbook of rail defects - Code 712 Rail Defects) prema izdanju UIC iz 2002. godine obuhvata defekte tipa head checking i squat [3]. Princip kodiranja defekata prikazan je na slici 7. U tabeli 1 predstavljen je način kodiranja defekata head checking i squat.

Usklađivanjem Uputstva 339 sa UIC Code 712 osiguralo bi se jedinstvo postupaka za utvrđivanje, prijavljivanje i klasifikaciju šinskih defekata i izradu statističkih pokazatelja o šinskim defektima u okviru jedinstvene evropske baze podataka, čiji je cilj razmena iskustava i razvoj jedinstvenih metodologija upravljanja održavanjem infrastrukture na nivou Evrope i šire.

A crack will have a certain detectable size (P-potential of crack development before detection). This depends on the detection technique used. From this size the propagation of the crack can be followed until it reaches the critical size where a rail break can be expected (F – failure due to breakage). The time or traffic load (expressed in million gross tons) between crack detection and rail break can be used to define the P-F interval (figure 6).

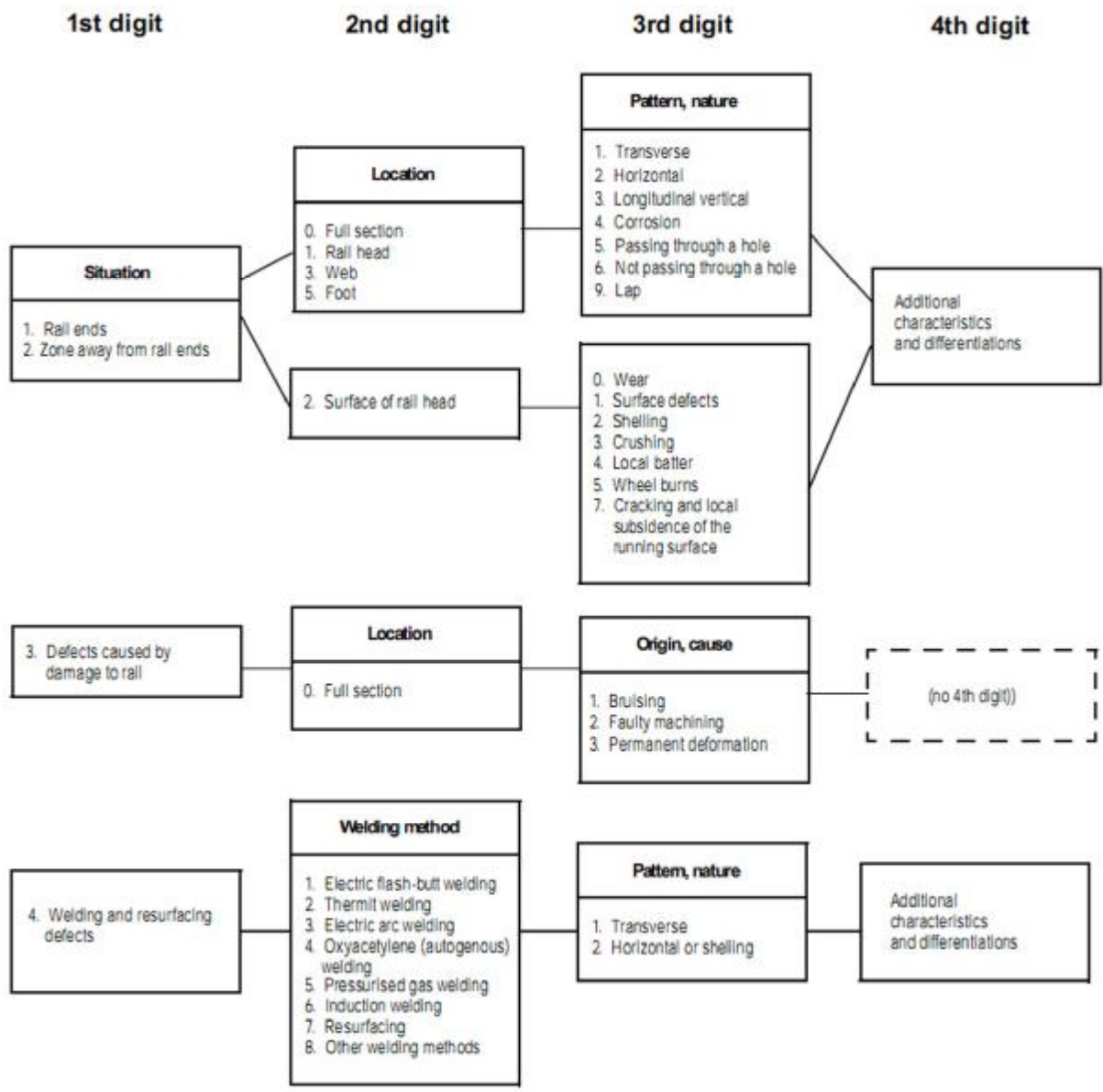
For all type of defects, crack growth rates can vary considerably. However simple crack growth models can be produced for transversal defects in the rail head area [5].

This paper presents and analyzes the occurrence of characteristic rail defects due to rolling contact fatigue, known as: head checking and squat. Belgrospi type of the defect is briefly presented. It is characteristic for high speeds. Terms head checking, squat and belgrospi are officially used in all of the languages of the world in scientific and technical literature without translation.

The defects mentioned above are not included in the Instruction 339 on unique criteria for track conditions control on the Serbian Railways network, which is still officially in use in Serbian Railways [11]. For now, there is no technical literature in Serbian that includes this field.

The Handbook of rail defects (UIC CODE 712 - Rail Defects) includes head checking and squat type of defects, according to the UIC issue from 2002 [3]. Rail defect coding system is shown on figure 7. Table 1 shows the principle of coding defects head checking and squat.

Synchronizing Instruction 339 with UIC Code 712 would ensure a unique procedure for determination, registration and classification of rail defects and creation of statistical parameters on rail defects within a unique European database, whose objective is exchange of experience and development of unique methodologies of infrastructure maintenance managing, on the European level and further.



Slika 7. Princip kodiranja šinskih defekata [3]
Figure 7. Rail defect coding system [3]

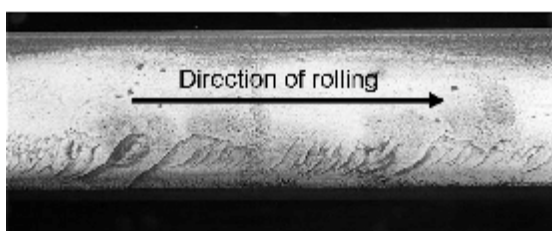
Tabela 1. Kodiranje defekata head checking i squat
Table 2. Classification and numbering of rail defects head checking and squat

1st digit	2nd digit	3rd digit	4th digit	Rail defect type and code
2 (defect away from rail ends)	2 (head)	2 (fissuring)	3 (scaling at the gauge corner)	Head checking 2223
		7 (cracking and local depression of the running surface)	-	Squat 227

2.1 Defekt tipa head checking

Ovaj defekt se javlja na spoljašnjoj šini u krivinama radijusa do 3000 m. Ipak, defekt se najčešće javlja pri radiusima krivina do 1500 m. Defekt se javlja na prelazu iz kotrljajuće površi na glavi šine (površina po kojoj se kotrlja točak šinskog vozila) u unutrašnju bočnu stranu glave. Defekt se uočava isključivo u kolosecima sa definisanim smerom vožnje (npr. dvokolosečna pruga) i sa velikim kvazi-statičkim opterećenjem po točku vozila (slika 8). Orijentacija prslina zavisi od smera vožnje.

Defekt šina usled zamora materijala u šinama ugrađenim u koloseke jednokolosečne pruge manifestuje se na sasvim drugačiji način [2]. Usled promenljivog smera vožnje zamor materijala se manifestuje kao bočno tečenje čelika glave šine (slika 9).



Slika 8. Izraziti primer oštećenja tipa head checking
Figure 8. Characteristic example of head checking rail defect

Head checking na šinama dvokolosečne pruge uočava se u vidu finih, kratkih, kosih, površinskih prslina na manje-više pravilnom rastojanju, koje najčešće iznosi 1-7 mm (ali i do nekoliko centimetara u zavisnosti od kvaliteta šinskog čelika). Pojava površinskih prslina ukazuje da ispod površine već postoje prsline, koje se prostiru do određene dubine i određenom smeru unutar glave šine.

Ukoliko se defekt ne otkloni na vreme, on napreduje dovodeći do odvajanja manjih ili većih delova šinskog čelika (slika 10). Razvijanjem prslina na dole, u krajnjem ishodu često dolazi do loma šine (slika 11).



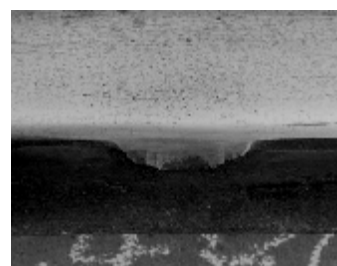
Slika 10. Head checking defekt sa odvajanjem čelika na zaobljenoj ivici glave šine
Figure 10. Head checking with the scaling (spalling)

Mogućnost napredovanja prslina do luskanja (slika 10) i loma šine (slika 11), ukoliko se ne primeni odgovarajuća strategija brušenja (u pravom trenutku i do najmanje neophodne dubine), višestruko povećava

2.1 Head checking

This defect occurs on the outer rail in the curves of radius up to 3000 m. However, the defect most frequently occurs in the curves of the radius of up to 1500 m. The defect occurs on gauge corner. Defect is distinguished exclusively on tracks with defined motion direction (for example, double track line) and with great quasi-static wheel load (figure 8). Fissure orientation depends on the direction of rolling.

Rail defect due to rolling contact fatigue on rails of the single track line manifests in an entirely different way [2]. Due to alterable direction of rolling, rolling contact fatigue manifests as lateral flow of the rail head steel (figure 9).



Slika 9. Bočno tečenje usled zamora materijala u glavi šine na jednokolosečnoj pruzi
Figure 9. Lateral flow of steel caused by rolling contact fatigue on the single track line

Head checking on the double track line shows as fine, short, raked, surface fissures at more or less regular distance, which is usually 1-7 mm (but up to a few centimetres, depending on the rail steel quality). Surface fissures point to existence of fissures already below the surface, extending until certain depth and in certain direction inside the rail head.

If the defect is not removed in time, it advances leading to detachment of pieces of rail (figure 10). Fissure advancing downwards often results in the breaking of rail (figure 11).



Slika 11. Lom šine usled razvoja head checking defekta
Figure 11. Rail break caused by the head checking

Unless adequate grinding strategy is applied (in the right moment and to the minimum depth necessary), the possibility of fissure advancement to the point of flaking (figure 10) and rail breakage (figure 11) increases many-

troškove održavanja gornjeg stroja (prerana zamena šine, progresivno propadanje geometrije koloseka), narušava pouzdanost i bezbednost železničkog saobraćaja. Zbog toga se u Evropi intenzivno sprovode teorijska istraživanja, laboratorijska merenja i merenja u koloseku. Praktična iskustva se sumiraju na osnovu statističke obrade podataka iz jedinstvenog prijavnog formulara za zamenu šine sa lomom, prslinom ili oštećenjem prema UIC CODE 712 (Prilog A).

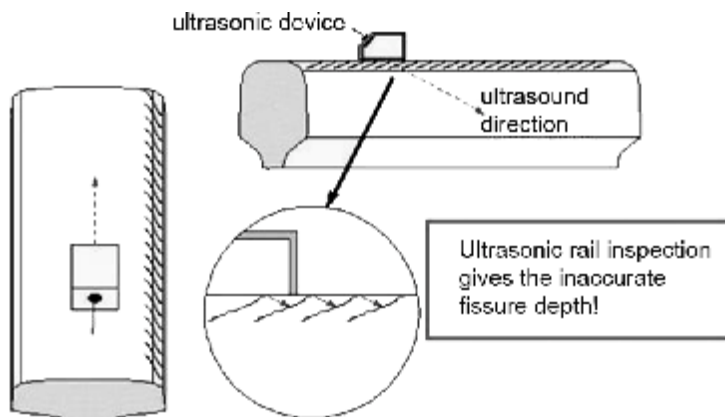
Nepoznavanje brzine razvoja prsline i nepouzdanost merenja dubine prsline uobičajenim postupkom ultrazvučnog ispitivanja (slika 12) [6] su problemi koji se u praktičnim uslovima rešavaju periodičnim ciklusima brušenja šine u skladu sa iskustvima svake železničke uprave. Za sada se pažnja usmerava na kritična područja (npr. spoljna šina u krivini i sl.), koja su iskustveno prepoznatljiva po mogućim koncentracijama naprezanja i u njima na kritična mesta (npr. prelaz kotrljajuće površine na glavi šine u unutrašnju bočnu stranu glave šine) gde se prema iskustvu mogu očekivati prsline usled zamora.

Interesantno je zapaziti da UIC CODE 712 kao meru za detekciju head checking defekta preporučuje ispitivanje ultra zvukom. UIC CODE 725 ispravlja ovaj previd i ukazuje da primenom ultra zvukom defekt može ostati neotkriven. Zato se preporučuje ručna kontrola, optički sistem i ispitivanje pomoću struje.

fold superstructure maintenance costs (early rail replacement, progressive deterioration of the track geometry) and violates reliability and safety of the railway traffic. Therefore theoretical research, laboratory measurement and track measurement are intensively being conducted in Europe. Practical experience is summed based on the statistical data processing from withdrawal form for broken, cracked or damaged rail according to UIC CODE 712 (Appendix A).

In practical conditions, periodical cycles of rail grinding according to experience of every railway management solves the problems of not knowing the speed of the fissure development and unreliable fissure depth measurement with the usual ultrasonic inspection procedure (figure 12) [6]. For now, the attention is focused on critical areas (for example outer rail in the curve and similar), which are empirically recognizable by eventual stress concentration, and critical places inside critical areas (for example, gauge corner) where according to experience fissures due to fatigue could be expected.

It is interesting to note that UIC CODE 712 recommends ultrasonic inspection as a measure for head checking defect detection. UIC CODE 725 corrects this oversight and shows that the defect can remain undetected with ultrasound application. Therefore, manual, optical system or eddy current inspection is recommended.



Slika 12. Nemogućnost primene ultrazvučnog ispitivanja za utvrđivanje dubine prsline head checking defekta [6]
Figure 12. Unreliable head checking fissures depth measurement with the usual ultrasonic inspection procedure [6]

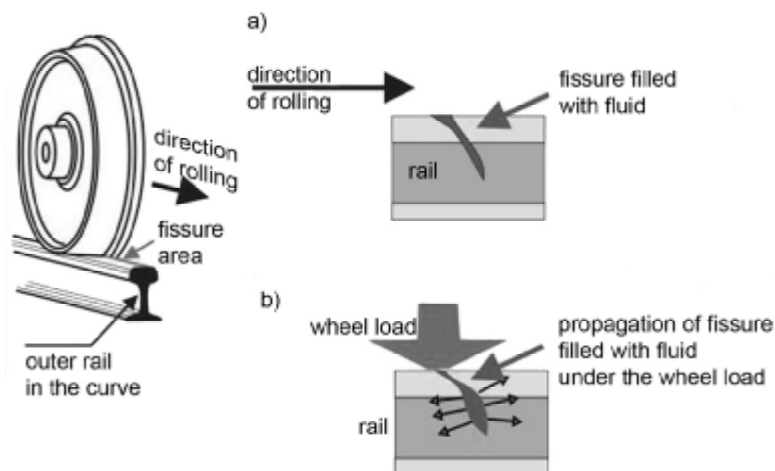
Jedna od uobičajenih preventivnih mera održavanja, koja se sprovodi na železničkim prugama je podmazivanje kako bi se smanjilo bočno habanje glave spoljašnje šine i habanje venca točka. Nažalost, ova mera pospešuje razvoj head checking defekta šine [1]. Usled prodiranja sredstva za podmazivanje u prsline (zajedno sa nečistoćama i atmosferskom vodom) i pritiska na zidove prsline pod točkom dolazi do bržeg napredovanja i širenja prsline (slika 13).

Brzina rasta defekta head checking ne može da se modeluje zbog problema detekcije u početnoj fazi.

One of the usual preventive maintenance measures used on railways is lubrication in order to decrease lateral rail wear of the outer rail and wheel flange wear. Unfortunately, this measure stimulates head checking rail defect [1]. Lubricant penetrating inside fissures (together with impurities and atmospheric water) and the pressure from the wheel on fissure walls lead to faster advancement and dilatation of fissure (figure 13).

The head checking defect speed growth cannot be modelled due to detection problems in the initial phase.

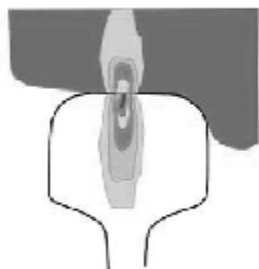
Fissure propagation due to fluid entrapment and pressurization



Slika 13. Širenje prsline usled prodiranja sredstva za podmazivanje u prslinu
Figure 13. Fissure propagation due to lubricant penetration

2.2 Defekt tipa squat

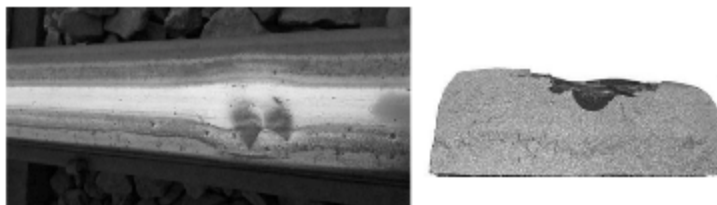
Defekt nastaje na šinama koloseka u pravcu, ili u krivinama radijusa $R \geq 3000$ m usled delovanja dinamičkog opterećenja od saobraćaja (slika 14), u zonama izrazitog kočenja i ubrzavanja vozila. Uočava se na kotrljajućoj površini kao proširenje i lokalno ulegnuće dodirne površine točak-šina i praćeno je tamnim mrljama (slika 15) i lučnim prslinama ili prslinama u obliku latiničnog slova "v". Zato se pored naziva squat u nemačkoj literaturi koristi i naziv "Schwarzer Fleck" (u prevodu: "crna mrlja"), jer se vizuelno uočava kao crna mrlja na sjajnoj ugllačanoj kotrljajućoj površini na glavi šine.



Slika 14. Krična zona za pojavu defekta tipa squat [5]
Figure 14. Squat emergence zone [5]

2.2 Squat

Squats are a rolling contact fatigue phenomenon which occur mainly on straight lines and curves of radius $R \geq 3000$ m with high shear stresses (figure 14), especially zones where accelerations and braking occurs. This defect is visible on the running surface of the rail head as a widening and a localised depression of the rail/wheel contact band, accompanied by a dark spot containing cracks (figure 15) with a circular arc or V shape. The term "Schwarzer Fleck" ("black stain") is also used in German literature because it is visually distinguished as a black stain on the glossy polished running surface.



Slika 15. Oštećenje tipa squat (izgled i poprečni presek)
Figure 15. A typical severe squat (view and cross section)

Tokom vremena prsline se širi ka unutrašnjoj strani glave šine. Napredovanje prsline se najpre ostvaruje pod malim uglom prema kotrljajućoj površini. Nakon što prsline dostigne dubinu 3 do 5 mm, povija se u poprečnom pravcu na dole i može da prouzrokuje lom (slika 16).

Ponekad se ovaj defekat javlja u kombinaciji sa naboranošću gornje površine glave šine, ili nastaje usled utiskivanja stranih tela u gornju površinu glave šine.

Ukoliko se defekt uoči u početnom stadijumu, može se ukloniti brušenjem i na taj način odložiti zamena šine.

With time, the crack is expanding towards inner side of the rail head. The cracks propagate inside the head, at first at a shallow angle to the surface. Then, when they reach 3 to 5 mm depth, they propagate downward transversely, producing the fracture of the rail (figure 16).

Sometimes this defect appears combined with corrugation on the running surface, or it originates due to embedment of foreign bodies in the upper surface of the rail head.

If the defect is noticed in the initial stadium, grinding can remove it and thus the rail replacement can be

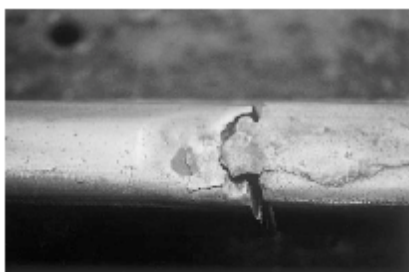
Samo u pojedinim slučajevima ovaj defekt se može sanirati navarivanjem. Ipak, najčešće se problem rešava zamenom šine.

2.3 Defekt tipa belgrospi

Ovaj defekt se javlja isključivo na prugama za velike brzine, kao efekat zamora šinskog čelika. Defekt je dobio ime prema prezimenima trojice ljudi, koji su prvi uočili ovaj fenomen na prugama za velike brzine u Nemačkoj: Belz (Belc), Grosmann (Grosman) i Spiegel (Špigel).

Defekt se javlja na naboranoj šinskoj glavi u vidu prslina akumuliranih na vršnim delovima naborane površi glave šine. Defekt se može opisati i kao mešavina nepravilno raspoređenih head checking defekata i minijaturnih defekata tipa squat (slika 17).

S obzirom na to da naboranost šine dubine 0.03 mm značajno povećava dinamičke sile koje deluju na šinu, upravo ova vrednost se propisuje kao granična za preduzimanje brušenja šine na prugama za velike brzine.



Slika 16. Lom šine usled oštećenja tipa squat
Figure 16. Example of breakage under a squat

Belgrospi defekt se može često uočiti na električno zavarenim spojevima i aluminotermijskim varovima kao i u području naboranosti glave šine.

Lokacija ovih defekata je proizvoljna i mogu da se pojave sukcesivno. U tom slučaju postoji rizik od višestrukog loma uz ispadanje većeg komada šine. UIC CODE 712 ne obuhvata ovaj defekt.

3 STRATEGIJE BRUŠENJA ZA OTKLANJANJE DEFEKATA USLED ZAMORA ŠINSKOG ČELIKA

Nega šine (eng. "rail-care", nem. "Schienenpflege") danas predstavlja rutinsku meru održavanja gornjeg stroja železničkih pruga u većini zemalja EU i ostatka sveta sa razvijenom železnicom (Japan, Rusija itd.), gde su prednosti ovakvog pristupa održavanju višestruko ekonomski dokazane kroz dugogodišnju praktičnu primenu i praćenje iskustava.

U svetu brušenje šina predstavlja rutinski deo nege šina i zasnovano je na ekonomskim principima. U početku se brušenje šina primenjivalo samo sporadično, za otklanjanje naboranosti površi glave. Vremenom reparacija šine brušenjem postaje redovna aktivnost održavanja gornjeg stroja sa posebnim akcentom na preventivnom delovanju.

Pravovremenim brušenjem uočenih površinskih prslina sprečava se njihov dalji razvoj. Treba naglasiti da

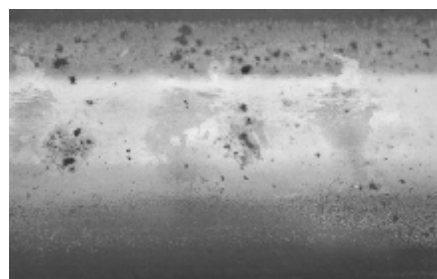
deferred. Only in some cases welding can repair this defect. Rail replacement most frequently solves the problem, though.

2.3 Belgrospi

This defect occurs only on high speed lines due to rolling contact fatigue. The defect was named after surnames of three persons who first noticed this phenomenon on high speed lines in Germany: Belz, Grosmann and Spiegel.

The defect occurs on the rail-head corrugation in the form of cracks accumulated on the ridges of the corrugation surface. Defect could also be described as a composition of unevenly distributed head checking defects and miniature squat defects (figure 17).

Since corrugation of 0.03 mm significantly increases dynamic forces affecting the rail, this value is set as a border value for rail grinding on high speed lines.



Slika 17. Defekt tipa belgrospi
Figure 17. Belgrospi

Belgrospi defekt can often be observed on electrically welded rail joints and aluminothermic welds as well as in the rail-head corrugation areas.

Location of these defects is random and they can occur successively. In that case there is a risk of multiple breaking with bigger pieces of rail going off.

UIC CODE 712 does not include this defect.

3. RINDING STRATEGIES FOR REMOVAL OF RAIL DEFECTS DUE TO ROLLING CONTACT FATIGUE

Today, rail-care is part of railway superstructure routine maintenance in most of the countries of the EU and the rest of the world with developed railway infrastructure (Japan, Russia etc.), where advantages of this maintenance approach are economically proved many times through long-term practical application and following experience.

Rail grinding is a routine part of rail-care worldwide and it's based on economical principles. In the beginning, grinding was only sporadically used, for running surface corrugation removal. With time, rail repair by grinding became a regular superstructure maintenance activity, with special emphasis on acting preventively.

Timely grinding of distinguished surface cracks prevents their further development. It is necessary to

efekat brušenja nije trajan. Nakon izvesnog vremena, ponovo dolazi do pojave prslina usled zamora materijala.

Strategija brušenja obuhvata primenu tehnike brušenja radi uklanjanja šinskog čelika izloženog zamoru materijala, u granicama proizvodnih tolerancija za odgovarajući poprečni profil šine.

Cilj primene strategije je produženje veka trajanja šine u koloseku, smanjenje ukupnih troškova održavanja koloseka i vozila, kontrola nivoa buke i vibracija od železničkog saobraćaja.

Strategija brušenja obuhvata preventivne, korektivne i ciklične aktivnosti.

Preventivne aktivnosti se preduzimaju pre nego se uoče defekti u zonama gde je njihova pojava iskustveno očekivana. Pored toga pod preventivnim aktivnostima podrazumevamo intervencije za koje se iskustveno zna da će njihova primena zadržati rast defekta u periodu između dve intervencije ispod usvojenog praga tolerancije.

Preventivno brušenje se preduzima nakon polaganja novih šina u kolosek pre prijema radova. Ukoliko se radi o zameni šine u postojećem koloseku, nove šine se mogu brusiti odmah ili par nedelja nakon ugradnje. Brušenjem glave šine uklanja se sloj debljine 0.3 mm.

Nemoguće je postići da se brušenjem novih šina nakon polaganja u kolosek u potpunosti isključi pojava oštećenja na gornjoj površini šine tokom eksploatacije.

Brušenje naboranosti glave šine i pojava nastalih usled zamora šinskog čelika spada u korektivne aktivnosti. Ove aktivnosti se planiraju i sprovode kada se prekoraci propisani prag tolerancije za odgovarajući defekt.

Cikličnim aktivnostima uklanja se sloj male debljine (0.1 do 0.2 mm) sa cele površi glave, odnosno do 0.6 mm u zonama oštećenja. Korekcije poprečnog profila šine rade se u uskim granicama tolerancije ± 0.3 mm.

Defekti nastali usled zamora materijala su fenomen koji se uporno ponavlja tokom eksploatacije šine. Zbog toga nega šine u ovom slučaju podrazumeva sprovođenje cikličnih aktivnosti tokom celokupnog veka trajanja šine. Ciklično se uklanja materijal u oštećenim zonama uz očuvanje poprečnog profila šine u uskim granicama tolerancije.

U zavisnosti od dubine oštećenja šine uklanja se materijal sa površine glave sa ciljem da se omogući kotrljanje točka po neoštećenoj površini čelika. Uklanjanjem materijala postupkom brušenja mora se održati poprečni profil šine kako bi se naponi u dodiru točka i šine održali u dozvoljenim granicama i osigurao stabilan tok vožnje.

Iskustvo je pokazalo da nakon polaganja novog koloseka interakcija točka i šine najčešće nije optimalna. Prosto superponiranje dozvoljenih tolerancija (profil šine, šinsko pričvršćenje itd.) može dovesti do poremećaja intaraksije.

Sve češća primena šine sa tvrdom glavom, koja ima veoma malo habanje, ima za posledicu duže prilagođavanje geometriji točka [4]. Zbog toga je brušenje novih šina u koloseku postalo standardna praksa na savremenim železnicama Evrope i sveta. Cilj je da se već na početku eksploatacije osiguraju optimalni uslovi i uklone uobičajene sitne neregularnosti nastale polaganjem koloseka (fine neravnine na zavarenim spojevima, oštećenja usled utiskivanja tucanika i sl.).

Poslednjih godina u Evropi se primenjuju specijalni modifikovani poprečni profili šina, tzv. "anti head

emphasize that the grinding effect is not permanent. After some time, cracks due to fatigue reoccur.

Grinding strategy applies grinding technique for removing rail steel exposed to fatigue, within limits of production tolerance for the corresponding rail profile.

The strategy objective is rail life extension, reduction of total track and vehicle maintenance expenses, and railway traffic vibration and noise level control.

Preventive, corrective and cyclic activities make the grinding strategy.

Preventive activities are undertaken before the defects are noted in the zones where their occurrence is empirically expected. Preventive maintenance also assumes interventions empirically known to hold the defect growth in a period between two interventions below the adopted tolerance threshold.

Preventive grinding is applied after laying new rails on the track before acceptance of works. If the rail has to be replaced on the existing track, new rails can be grinded right away or a few weeks after the assembly. Rail-head grinding removes a 0.3 mm thick layer.

It is impossible to completely exclude damage on the upper rail surface by grinding the new rails after they are laid on the track.

Rail head corrugation grinding and phenomena due to rolling contact fatigue are corrective activities. These activities are planned and applied when the established tolerance threshold for the corresponding defect is exceeded.

Cyclical activities remove a thin layer (0.1 to 0.2 mm) from the entire head surface, i.e. up to 0.6 mm in the damage zones. Rail cross profile corrections are performed within the narrow tolerance limits, ± 0.3 mm.

Defects due to rolling contact fatigue is a phenomenon that persistently reoccurs during the rail exploitation. Therefore, in this case rail care assumes applying cyclic activities throughout entire rail life span. The material is cyclically removed in the damaged areas while maintaining rail cross profile within narrow tolerance limits.

Depending on the depth of the rail damage, the material from the head surface is removed in order to enable wheel rolling on the undamaged steel surface. Rail cross profile must be maintained after removing material by grinding in order to maintain the stress in the wheel/rail contact point within tolerable limits and ensure vehicle ride quality.

The experience shows that after laying the new track, most frequently wheel/rail interaction is not optimal. Mere superposition of allowed tolerances (rail profile, fastening system, etc.) can lead to interaction perturbation.

A consequence of frequent application of the hard head rail with very little wear is longer adaptation to the wheel geometry [4]. That is why grinding of new rails has become a standard practice on modern railways throughout Europe and around the world. The objective is to ensure optimal conditions and remove the usual small irregularities due to track laying (fine roughness on welded rail joints, damage due to impressing railway ballast grains and similar) already on the beginning of the exploitation.

In the past few years special modified rail cross profile, so called "anti head checking profile", has been applied in Europe. So far there is no unique anti head

checking profil". Za sada ne postoji jedinstveni anti headchecking profili šine, već svaka železnička uprava za svoje potrebe i u skladu sa sopstvenim iskustvom razvija profil šine reprofilisanjem standardnih profila proizvedenih u skladu sa EN 13674-1: 2003: Railway applications - Track - Rail - Vignole railway rails 46 kg/m and above. Reprofilisanje šine se vrši brušenjem uz veoma stroge tolerancije, s obzirom na izrazitu osetljivost geometrije u dodiru točka i šine. Brušenjem zone u kojoj se tokom eksploatacije usled zamora šinskog čelika očekuje pojava kosih kratkih prslina na prelazu kotrljajuće u unutrašnju bočnu stranu glave šine (head checking defekt) produžava se vek trajanja šine u koloseku i povećava bezbednost saobraćaja.

Na prugama za težak železnički saobraćaj već dugo vremena se uspešno primenjuje postupak brušenja vozne ivice na glavi šine u kritičnoj zoni za pojavu defekta usled zamora materijala (slika 18).

Pojedine železničke uprave u Evropi razvile su u poslednje vreme specijalne profile šine koji uklanjaju šinskog čelika brušenjem iz kritične zone ostvaruju slobodan prostor između venca točka i vozne ivice šine. Geometrija profila se razlikuje u skladu sa lokalnim specifičnostima svake železnice (slika 19) [9].



Slika 18. Kritična zona za pojavu defekta tipa head checking [5]
Figure 18. Head checking emergence zone [5]

U Francuskoj se koriste dva tipa profila za redukciju zamora šinskog čelika: AHCP (Anti-Headcheck-Preventif) i AHCC (Anti-Headcheck-Correctif).

AHCP profil se koristi kao ciljni profil pri brušenju novih šina koje se nalaze u zonama očekivane pojave head checking defekata. Pored toga ovaj profil se koristi i u slučaju kada se još uvek vizuelno ne uočavaju posledice zamora šinskog čelika na glavi spoljne šine koloseka u krivini.

AHCC profil se koristi u slučaju kada se na šinama već uočava zamor materijala u početnoj fazi. Profil se odlikuje značajnijim slojem koji se uklanja brušenjem vozne ivice (npr. 1 mm umesto 0.3 mm u odnosu na profil 60E1 pri poprečnom nagibu šine 1:20).

Švedska, Holandija, Austrija i Nemačka razvile su, takođe, anti head check profile prema lokalnim uslovima i iskustvima.

4 ZAKLJUČNA RAZMATRANJA

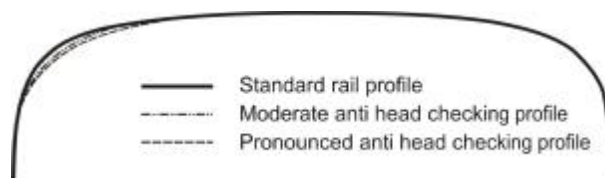
Defekti šine usled zamora pod točkom vozila predstavljaju ozbiljnu opasnost za železnički saobraćaj širom sveta.

Upravljanje šinskim defektima zasniva se na planskoj kontroli šina u koloseku. Prema ustaljenoj praksi inspekcija šina se obavlja po unapred utvrđenom planu. Ova-

checking rail profile, but for their own needs and according to their own experience, every railway management develops a rail profile by re-profiling standard rail profiles manufactured according to EN 13674-1: 2003: Railway applications - Track - Rail - Vignole railway rails 46 kg/m and above. Rail re-profiling is performed by grinding within very strict tolerances, since geometry is very sensitive in the wheel/rail contact. Grinding the area where short raked fissures on gauge corner due to rolling contact fatigue are expected during exploitation (head checking defect), extends rail life and increases traffic safety.

For a long time already, the grinding procedure of the running surface of the rail in the critical area for occurrence of defects due to rolling contact fatigue is successfully applied on the railways with heavy traffic (figure 18).

Some railway managements in Europe have recently developed special rail profiles where removing rail steel from the critical zone by grinding creates free space between the wheel flange and the running surface of the rail. Profile geometry differs according to the local specifics of every railway (figure 19) [9].



Slika 19. Opšti princip anti head checking profila
Figure 19. General principle of anti head checking profile

Two profile types for rolling contact fatigue reduction are used in France: AHCP (Anti-Headcheck-Preventif) and AHCC (Anti-Headcheck-Correctif).

AHCP profile is used as a target profile while grinding new rails in the areas of the expected occurrence of head checking defects. Moreover, this profile is also used when consequences of rolling contact fatigue are still not visible on the outer rail head in the curve.

AHCC profile is used when fatigue in the initial phase is already discernable on the rails. The profile is characterized by a significant layer which is removed by grinding the running surface (for example, 1 mm instead of 0.3 mm in for the profile 60E1 at the rail cant of 1:20).

Sweden, Holland, Austria and Germany have also developed anti head checking profiles according to the local conditions and experience.

4 FINAL CONSIDERATIONS

Rail defects due to rolling contact fatigue are a serious danger for railway traffic worldwide.

Defect management is based on the definition of rail test schedule. Traditionally, rail testing has been performed at fixed time intervals. However, this method does not always result in the optimum system in respect

kav pristup nije optimalno rešenje ni u pogledu troškova, ni u pogledu sigurnosti. Nažalost, upravo ovakav koncept primenjuju Železnice Srbije prema postojećoj tehničkoj regulativi.

Pored toga, postojeća tehnička regulativa je zastarela i ne odgovara zahtevima bezbednosti savremenih konvencionalnih pruga za mešoviti saobraćaj. Postojećom tehničkom regulativom nisu obuhvaćeni defekti prikazani u ovom radu (defekt belgrospi nije od interesa za konvencionalne pruge).

U radu je ukazano da optimalna periodičnost inspekcije šina zavisi od lokalnih uslova: konstrukcija gornjeg stroja, brzina, osovinskog i saobraćajnog oprećenja. To znači da se ne mogu nekritički prihvatiti tuđe strategije održavanja.

Za određivanje optimalne periodičnosti mogu se koristiti različiti matematički modeli zasnovani na teoriji rizika ili analizi troškovi/dobit.

Za razvoj modela zasnovanih na definisanom nivou prihvatljivog rizika upravljač infrastrukture mora da obezbedi sledeće podatke:

- broj šinskih lomova u vremenskom intervalu (npr. u toku jedne godine),
- šinske defekte u vremenskom intervalu,
- profil šine, kvalitet čelika i datum proizvodnje,
- maksimalno dozvoljenu veličinu defekta,
- bezbedno vreme između pojave i kritične veličine defekta,
- pouzdanost detekcije,
- podaci o saobraćaju.

Upravljač infrastrukture mora da definiše prihvatljiv nivo rizika iskazan kroz broj dozvoljenih lomova šine po jedinici dužine u određenom vremenskom intervalu.

Za razvoj modela zasnovanih na analizi troškovi/dobit upravljač infrastrukture treba da obezbedi sledeće podatke:

- troškovi za ispitivanja šine,
- troškovi za saniranje loma šine,
- troškovi prekida saobraćaja zbog loma šine,
- troškovi korektivnog održavanja defekata nastalih pod saobraćajem,
- troškovi iskliznuća vozila zbog loma šine,
- verovatnoća nastupanja iskliznuća vozila zbog loma šine.

Metod ispitivanja šine mora da odgovara tipu defekta. Ultrazvučna ispitivanja (preporučena kao univerzalna prema [11] i odgovarajuća prema [3]) ne mogu obuhvatiti sve defekte i izrazito zavise od spoljne temperature. Pored ultrazvučnog ispitivanja treba koristiti vizuelnu i druge vrste inspekcije prema [5].

U radu je ukazano da upotreba šine sa tvrdom glavom u krivini i podmazivanje radi smanjenja bočnog habanja, može da dovede do progresivnog razvoja head checking defekta.

Sprovođenje preventivnog, korektivnog i cikličnog brušenja preporučuje se kao mera za produženje veka trajanja šine u koloseku, smanjenje ukupnih troškova održavanja koloseka i vozila, kontrolu nivoa buke i vibracija od železničkog saobraćaja prema evropskim standardima.

Za sprovođenje zaključaka ovog rada neophodna je hitna harmonizacija propisa iz oblasti održavanja železnica sa evropskom regulativom, uz poštovanje lokalnih specifičnosti i ograničenja.

of cost and safety. Unfortunately, Serbian Railways are applying precisely this kind of concept according to technical regulations.

Moreover, the existing technical regulations are outdated and don't correspond to the safety requirements of the modern mixed traffic conventional lines. Defects illustrated in this paper are not included in the technical regulations (belgrospi defect is not of interest for conventional lines).

This paper emphasizes that the optimum test interval is based on the local conditions: superstructure construction, vehicle speed, axle load and traffic load. Foreign strategies cannot be uncritically accepted.

Different models can be used to find the optimum test interval. Some models are based on a defined risk level. Other models use cost/benefit analyses.

Defect management models based on a defined risk level require certain input parameters:

- historical rail breaks per time unit (e.g. breaks per year),
- historical in service rail defects per time unit,
- profile, steel and age of rail,
- maximum allowed defect size,
- safe time between detectable and critical defect size,
- detection reliability,
- traffic data.

The infrastructure manager must define the acceptable risk level in terms of number of rail breaks per track length unit over a given period.

In case of a cost/benefit model, the infrastructure manager must define the following parameters:

- rail testing costs,
- costs for repairing rail breaks,
- costs for traffic interruptions caused by rail breaks,
- cost for repairing in service rail defects,
- costs related to a derailment caused by rail break,
- probability of having a derailment caused by a rail break.

Rail inspection method must correspond to the type of the defect. Ultrasonic inspection (recommended as universal according to [11] and adequate according to [3]) cannot include all the defects and they very much depend on the outer temperature. Apart from ultrasonic inspection, visual and other types of inspection should be used according to [5].

This paper indicates that the use of hard head rail in the curve and lubrication in order to decrease lateral wear, can lead to a progressive development of the head checking defect.

Preventive, corrective and cyclic grinding is recommended as a measure to prolong rail life, decrease total track and vehicle maintenance expenses, control railway traffic vibration and noise levels, according to European standards.

An urgent harmonization of railway maintenance regulations with European regulations is necessary for pursuing the conclusions of this paper, while respecting local specifics and limitations.

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REZIME

ŠINSKI DEFEKTI USLED ZAMORA MATERIJALA

Zdenka POPOVIĆ
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Sa porastom brzina, osovinskog i saobraćajnog opterećenja na savremenim železničkim prugama raste dinamičko opterećenje. Zbog velikih kontaktnih napona u dodiru točka i šine, pojava defekata šine usled zamora materijala postaje sve izraženija. Brušenjem šina uklanja se materijal u očekivanoj, ili uočenoj zoni zamora čelika i vrši reprofilisiranje geometrije poprečnog preseka šine. Oblik geometrije reprofilisane šine nije jedinstven, već izrazito zavisi od strategije održavanja. Ipak, cilj svih strategija brušenja je jedinstven. To je namera da se odloži i uspori ponovna pojava defekta šine u koloseku. Ovakva strategija održavanja zahteva ponavljanje aktivnosti brušenja, koje spadaju u "negu šine". Na Železnici Srbije još uvek ne postoji razvijena strategija održavanja gornjeg stroja železničkih pruga koja uključuje aktivnosti nege šine u koloseku. U ovom radu se iznose iskustva železničkih uprava u Evropi i daje pregled i analiza rezultata istraživanja iz oblasti šinskih defekata usled zamora materijala (head checking, squat, belgrospi).

Ključne reči: železnica, održavanje, šina, brušenje, head checking, squat, belgrospi

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SUMMARY

RAIL DEFECTS DUE TO ROLLING CONTACT FATIGUE

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Dynamic load on modern railways is increasing with speed, traffic and axle load. Defects due to rolling contact fatigue are becoming more expressed because of high wheel/rail contact stress. Rail grinding removes the material in expected or distinguished fatigue area and re-profiles rail cross section geometry. Re-profiled rail geometry is not unique; it depends heavily on the maintenance strategy. However, the objective of all rail grinding is unique: the intention to defer and delay rail defect recurrence. Such maintenance strategy requires the repetition of grinding activities, which are part of "rail-care". Serbian Railways still don't have a developed railway superstructure maintenance strategy which includes rail-care activities. This paper presents the experience of railway managements in Europe and gives an overview and analysis of research results in the area of rail defects due to rolling contact fatigue (head checking, squat, belgrospi).

Key words: railway, maintenance, rail, grinding, head checking, squat, belgrospi