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RAIL DEFECTS HEAD CHECKING ON THE SERBIAN RAILWAYS

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Preliminary notes
The rail defects due to rolling contact fatigue represent serious safety hazard for rail traffic all around the world. That hazard is more distinct on railways without adequate maintenance strategy, with the increase of wheel/rail contact stresses and with decreasing wear of rail steel. This paper analyses the example of sporadically conducted maintenance and its negative consequence - the appearance of head checking (HC) rail defect on the Serbian Railways. The research of the HC defects was performed by using the visual inspection of rails in service and eddy current testing in the laboratory. The paper points out the importance of early detection of the HC rail defects for the effective defects management of rails in service. It researches the real limits of non-destructive methods for detecting HC defects in track. Combining several non-destructive testing methods is recommended for efficient rail inspection.

Keywords: *head checking, inspection, rail defects, railway, rolling contact fatigue*

Tračnička oštećenja tipa "head checking" na Željeznicama Srbije

Prethodno priopćenje
Tračnička oštećenja uslijed kontaktnog umora materijala pri kotrljanju predstavljaju ozbiljnu prijetnju za sigurnost željezničkog prometa diljem svijeta. Opasnost je izraženija na željeznici bez odgovarajuće strategije održavanja, s povećanjem naprezanja u kontaktu kotača i tračnice, a sa smanjenjem habanja tračnice. U radu se analizira primjer sporadično provedenog održavanja i njegove negativne posljedice – pojava tračničkog oštećenja tipa "head checking" (HC) na Željeznicama Srbije. Istraživanje HC oštećenja izvedeno je pomoću vizualnog pregleda tračnica u kolosijeku i ispitivanja u laboratoriju uz pomoć vrtložne struje. U radu se ukazuje na važnost ranog otkrivanja HC tračničkih grešaka za učinkovito upravljanje tračničkim oštećenjima u kolosijeku. Istražuju se realne granice nerazornih metoda za otkrivanje HC tračničkih oštećenja u kolosijeku. Za učinkovitu inspekciju tračnice preporuča se kombiniranje nekoliko nerazornih metoda testiranja.

Ključne riječi: *"head checking", inspekcija, kontaktni umor materijala pri kotrljanju, oštećenja tračnica, željeznica*

1 Introduction

Rail rolling contact fatigue (RCF) is an actual problem in high speed, mixed and heavy haul railways around the globe [1, 2]. Fatigue occurs in rail steel when the stress is above a certain level and when the number of traffic loading cycles is high enough. The load needed to trigger fatigue damage is lower than that for static failure. The crack nucleation (the origin or starting point of a defect) can occur at the rail head surface or at subsurface. The subsurface-initiated cracks occurred more frequently in the past due to non-metallic oxide inclusions in rail steel. When inclusions exist in the material they can become a centre of stress concentration and nucleate cracks. The development of steel making technology has reduced rolling contact fatigue defects associated with non-metallic oxide inclusions. Nevertheless, RCF cracks initiating on or very near to the rail surface, which are not associated with any specific imperfections and faults in the material, are a complex problem in modern railways. The RCF phenomenon threatens the traffic safety and increases the cost of rails maintenance: it may lead to expensive rail grinding, premature removal of rails and complete rail failure. The major occurrence of the RCF rail defects are head checkings and squats.

Since 1987 this complex phenomenon has been the subject of a research programme of the European Rail Research Institute [3]. This research has contributed to a better understanding of the phenomenon and to establishment of a uniform terminology in the UIC Rail Defect Catalogue [4]. Finally, the Handbook of rail defects [4] includes "head checking" and "squat" as types of rail defects due to rolling contact fatigue. The study [3] proposed a unique name for defects in order to avoid the current confusion in terminology. For this reason, the terms "head checking" and "squat" are officially used in all of the languages of the world in scientific and technical literature without translation. Experimental research of the influence of rail steel grade on wear and RCF shows that it is possible to reduce RCF and wear by using higher steel grades [2, 5, 6]. On the other hand, studies have shown the importance of wear for producing large thin metallic flakes and removing surface micro-cracks [7]. Anyway, researches have proven that none of the laboratory techniques for determining the rolling contact fatigue resistance of rail steel could reproduce all of the necessary service loading conditions [3].

As a part of the research project [8], a sensitivity analysis was performed to demonstrate how different traffic and track conditions affect a crack growth rate. A crack will have a certain detectable size which 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. 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 (P - potential of crack development before detection, F - failure due to breakage). For all type of defects, crack growth rates can vary considerably. However simple crack growth models can be produced just for transversal defects in the rail head area [9].

Many studies have been carried out on the relationship between HC occurrences and contact geometry [1, 10÷13]. It is expected that rail grinding, better track and bogie maintenance, as well as bogies designed to reduce the tractive forces required for curving, will be sufficient to alleviate RCF failures in curves.

Well known traffic accident happened in Hatfield on October 17th 2001. The cause of the accident is the rail breaks due to the numerous HC cracks [14]. After this disaster, EU began with intense safety inspections. Special attention is drawn on HC and squat rail defect.

Subject of research in this paper are the HC rail defects on the Serbian Railways. HC appears by default on the outer rail in the curves of radius up to 3000 m. However, most frequently it occurs in the curves of the radius of up to 1500 m, on gauge shoulder and gauge corner. Defect is distinguished exclusively on tracks with a defined motion direction (for example, double track line). The coding system in accordance with the [4] is shown in Tab. 1. The position of HC rail defects on the outer rail head in a curve is shown in Fig. 1.

Table 1 The coding and position of rail defects HC

Position of digit in the code 2223:		The meaning of digit in the code:
1st digit	2	Defect zone away from rail ends
2nd digit	2	Surface of rail head
3rd digit	2	Shelling
4th digit	3	Fissuring and/or scaling at the gauge corner
Head checking/Fissuring/Scaling at the gauge corner		

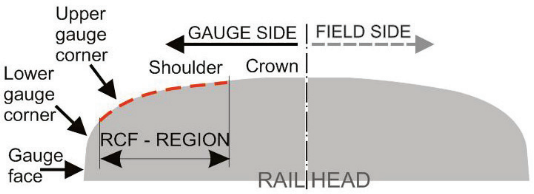

Figure 1 The characteristic RCF – region at the outer rail head in a curve [15]

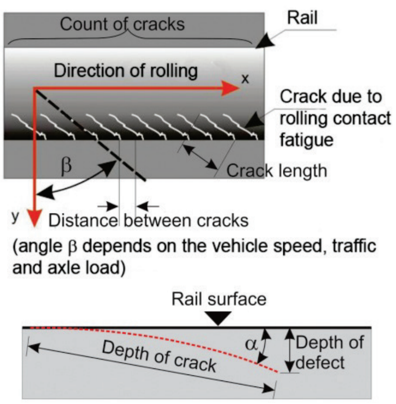

Figure 2 The typical orientation of HC fissures on the rail head [15]

The HC phenomenon is caused by lateral contact force and geometrical spin [11]. It occurs just below the upper surface of the rail head (≤ 0,1 mm), progresses rapidly upwards and reaches the upper head surface. Under the traffic load the cracks can be directed down with the risk of multiple rail fractures. The HC defect 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 out the fissures already exist below the surface, extending to certain depth and in certain direction inside the rail head. With increasing rail hardness the spacing between the cracks is reduced [5]. Orientation of HC cracks is shown in Fig. 2 [15]. It is especially dangerous when cracks run in very flat angles of approximately 15° into the rail head and the cracks distance is reduced to 0,5 mm. In this case multiple rail fractures may occur, which always leads to train derailment.

The standard life cycle of rails can be reduced to only 2 ÷ 3 years, if the adequate maintenance measures against HC defects are not taken at the time [15, 16]. Despite this, the Serbian technical regulations for the infrastructure maintenance do not include the rail defect HC. This study is of great importance and actuality for the Serbian Railways and the EU railway network.

2 Detection of the HC defects

The visual inspection of HC defects is conducted on the sections: Belgrade Centre – New Belgrade (from km 0+700 to km 2+854) and Belgrade – Šid – state border (from km 4+446 to km 13+400). According to UIC CODE 700, category of railway is D4: mass per axle P=22,5 t and mass per unit length p=8,0 t/m. Both are double track lines for mixed traffic. It was applied ballasted railway track system with rigid rail fastening system type "K" and wooden sleepers.

The research was conducted on sections with the poor quality of track geometry (classes B and C in accordance with Instruction 339 on unique criteria for track conditions control on the Yugoslav Railways network) and with the conditions for the occurrence of HC defect: mixed traffic, curves with radius R<1500 m, standard quality of rails in accordance with [17 ÷ 19]. Observed HC are classified according to crack length on the rail head surface.

The rail sections with 50 m length are classified with respect to the maximum crack length in accordance with Tab. 3 [11]. Information about HC defects, which were observed during the visual inspection, is entered in the form shown in Tab. 2 and saved in a database. The form was created for this research and its use in practice is proposed.

Table 3 The severity classification of HC defect [11]

Crack length	Severity
< 10 mm	Light defect (L)
10 – 20 mm	Medium defect (M)
20 – 30 mm	Heavy defect (H)
30 mm or more	Severe defect (S)

Special attention is focused on outer rail in curves. Rail switches [20], rail weld zones, and expansion joints should also be carefully investigated.

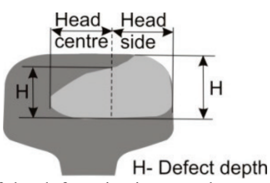

Figure 3 Definition of the defect size in accordance with UIC Code 72

After the visual inspection, the rail sample (rail type 60 E1, steel grade 900, length 98 cm of removed rail from track with specific HC cracks) was tested by eddy current (EC) testing in the Laboratory JAT in Belgrade. The rail sample was treated by sandblasting prior to the laboratory testing. The testing should determine the reliability of visual inspection (Fig. 3 and Tab. 4).

Table 2 The form for HC defects

1. General information about HC defect (Code number: 2223)		
Damaged rail ☐	Cracked rail ☐	Broken rail ☐
(Any rail which is neither cracked nor broken, but which has other defects, generally on the rail surface [4].)	(Any rail which, anywhere along its length and irrespective of the parts of the profile concerned, has one or more gaps of no set pattern, apparent or not, the progression of which could lead to breakage of the rail fairly rapidly [4].)	(Any rail which has separated into two or more pieces, or a rail from which a piece of metal becomes detached, causing a gap of more than 50 mm in length and more than 10 mm in depth in the running surface [4].)

2. Precise location of the defect in the track and date			
Line:			
Section:	from km ....+ .... to km ....+		
Track:	Left track ☐	Right track ☐	One track ☐
Rail:	Left rail ☐	Right rail ☐	
Kilometre point	From km ....+ .... to km ....+		
Date the defect was discovered:	Date the defect was repaired:	Date the broken rail was removed:	

3 Detection method			
Visual inspection ☐	Ultrasonic testing ☐	Eddy current testing ☐	Other means of detection:

4. Characteristics of the line		
Layout:	Straight line ☐	Curve ☐, Curve radius R= Outer (high) rail in the curve ☐ ; Inner (low) rail in the curve ☐
UIC group classification, according to UIC CODE 700:		A' ☐ , A" ☐, A ☐, B1☐, B2 ☐, C2 ☐, C3 ☐, C4 ☐, D2 ☐, D3 ☐, D4 ☐
Maximum speed: V= km/h		Temporary reduced speed: V= km/h Date: from to

5. Characteristics of the track				
Year laid:				
Method of laying:		Standard sections ☐		Continuous welded rail ☐
Rail fastening:	Type:		With base plates ☐	Without base plates ☐
Type of sleepers:	Wooden ☐	Concrete ☐	Metallic ☐	Slab track ☐
Location:	Open line ☐	Station ☐ Name: km + to km +	Tunnel ☐ Name: km + to km +	Bridge ☐ Name: km + to km +
Type of joint : -	Ordinary ☐	Junctioned ☐	Insulated ☐	Glued insulated ☐

6. Characteristics of the rail				
Rail condition:		New rail ☐		Reused rail ☐
Rail profile:	49 E1 ☐	60 E1 ☐	Other:	
Length of rail:	Length of new rail: .....m	Length of reused rail: .....m	Length of replaced rail: .....m	
Steel grade:	(700) R 200 ☐	(900) R 220 ☐	(900 A) R 260 ☐	
	(900 B) R 260 Mn ☐	(1100) R 320 Cr ☐	(900 A (HH)) R 350 HT ☐	R350 LHT ☐
Marks:	Rolling marks (in relief)		Stamped marks (embossed)	
Manufacturing process			Total gross tonnage borne	

7. Characteristics of welds or resurfacing		
Weld removed ☐	Weld repaired ☐	
Length of replacement rail:		
Profiles of the rails on either side of the weld:		
Steel grade of the rails on either side of the weld:		
Resurfacing:	at rail end ☐	away from rail end ☐

8. Action taken		
Keep rail under inspection ☐	Rail removed on	Rail despatched to ....

The procedure of EC testing is based on the electromagnetic interaction between the magnetic field of a test sensor and the currents induced in the metallic material. The EC field variations are caused by inhomogeneity in the rail steel surface and subsurface. These variations are used for sizing the HC crack depths (Fig. 2). The device Phasec 2200 for general eddy current testing was used for rail testing (NDT Laboratory JAT in Belgrade, 2012) and it is shown in Fig. 4. Standard probe was used at operating frequency of 500 kHz.

Table 4 Categorisation of HC defects by size

Category 0: Broken rail; **Activity**: Prohibition of traffic and immediate removal of the broken rail.
Category I: Defect size – Rail head centre: $H > 5$ mm, or rail head side: $H > 20$ mm **Activity** : Immediate removal of the rail (a maximum deadline of 2 weeks may be tolerated; by reinforcing the rail with fishplates or clamps can this deadline be extended to 6 weeks).
Category II: Defect size – Rail head side: 5 mm $< H \leq 20$ mm **Activity**: Removal of the rail within a time limit not exceeding 12 months (by reinforcing the rail with fishplates or clamps can defects remain in the track until an inspection carried out as a part of a regular inspection cycle placed the defect in a higher category).
Category III: Defect size – Rail head side: $H \leq 5$ mm **Activity** : Keep rail under inspection. These defects do not require repair but should be recorded and examined during the normal inspection cycles.

Figure 4 The device Phasec 2200 for rail testing using the EC

3 Results of the visual inspection and eddy current testing

HC defects were found on expected places: outer rail in curves R = 600 ÷ 800 m. Typical RCF region was observed in the outer rail, on the gauge side, in the gauge corner, usually between 25 mm and 35 mm in regard to the axis of symmetry of the rail cross-section.

The defect was more severe on steel grade 900 comparing with grade 700. On the certain sections HC was registered only two years after the laying of new rails with grade 900. The defect intensity is more significant on sections with high traffic load.

However, HC defect also appeared on unusual places: straight track sections, inner rail in curves, parts of the main track in rail switches and welded rail joints. The following examples present only the appearance of HC defects in non-standard locations.

The HC defects were registered on the left straight track of the railway section New Belgrade – Zemun, from km 6+630 to km 6+640 (Fig. 5). Rails 49 E1 (previous profile S 49) with steel grade 700 were made in Zenica, in 1969. Rails are currently in use for over forty years with high traffic load accumulation (there are no statistical data on traffic load accumulation in [21]).

Figure 5 Light HC defect on the straight track section (1 ÷ 4 cracks / 1 cm, length of 5 ÷ 10 mm)

HC defect was observed on both rails on the straight track section in the tunnel "Bežanijska kosa". The rails are of the same quality and same age as in the previous example. The defect is severe: 1 ÷ 5 cracks/1 cm. The spalling is observed sporadically due to the small distance between the cracks. Crack lengths are from 5 mm to 50 mm. The defect is difficult to detect and photograph due to darkness in the tunnel.

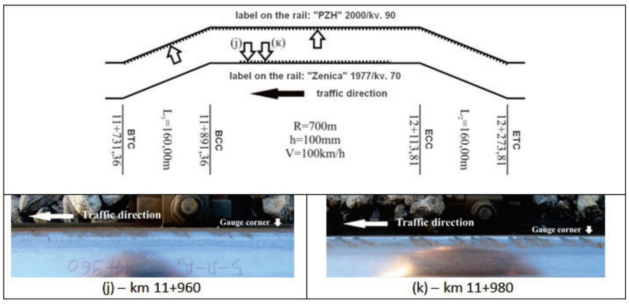

Figure 6 HC defects on the outer and inner rail in a curve

HC defect was observed on both rails (Fig. 6), on the railway section Zemun – Zemunsko polje, in the curve with radius R = 700 m (the left track, km 11+731,36 – 12+273,81). This line was designed for maximum speed of 120 km/h, in 1978. The cant of outer rail amounted to 145 mm. Speed was reduced for a long time at 40 km/h due to poor track geometry. Speed was increased to 100 km/h, and the rail cant was reduced to 100 mm in 2011. New outer rail was installed in October 2004. The defect is observed along outer rail in the curve. The defect is medium severe: 4 ÷ 5 cracks/1 cm, crack length of 10 ÷ 20 mm. The defect is observed on most parts of inner rail in the circular curve: 1 ÷ 2 cracks /1 cm, crack length of 5 ÷ 20 mm. Figure 6 shows PZH rails made by the Chinese producer PZC Steel that are known to be susceptible to corrugation and occurrence of cracks at the driving surface [22].

HC defect was also noted in some rail switches in stations "New Belgrade" and "Zemun". The reason for this can be found in irregular track geometry and worn out elements of switches [21]. The appearance of defects in Fig. 7 is untypical because the HC appeared on the right stock rail and on the right switch rail. A switch was incorporated into the track in 1993. All rails in the switch have the steel quality 700. The severe defects are observed: crack lengths from 5 mm to 35 mm and 2 ÷ 5 cracks/1 cm.

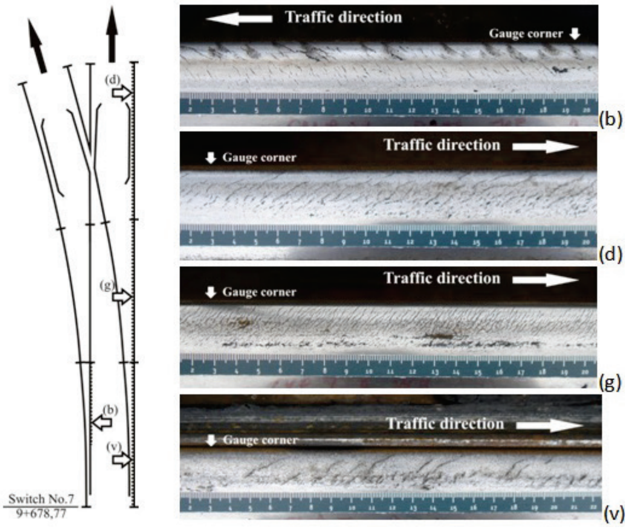

Figure 7 Untypical HC defects in the rail switch number 7 in station "Zemun", km 9+678,77

Also, HC defects are observed in the area of aluminothermic and electrical – resistant welded joints. For example, they are identified on the left track, in the area of electrical – resistant welded joints, in the curve (km 0+752,77 – 1+174,99), on the railway line Belgrade Centre – New Belgrade. The typical RCF - region is covered by lubricant along the entire length of the curve. Therefore the defects are hardly visible and visual inspection method was improved using fluorescent penetrates on the clean rail surface.

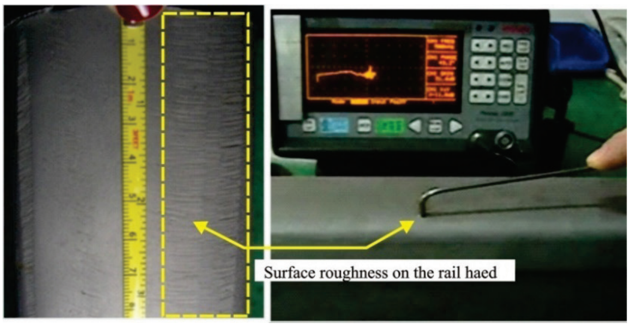

Figure 8 The surface roughness detection using the EC and the rail sample for testing

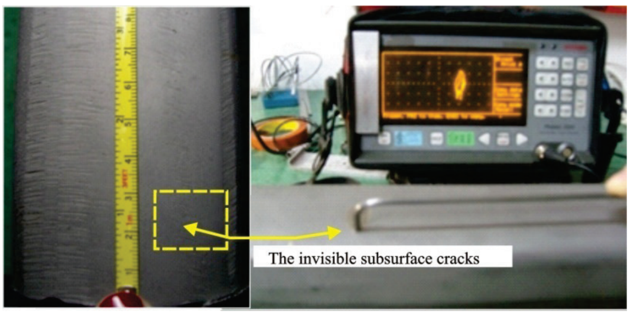

Figure 9 The subsurface cracks detection using the EC and the rail sample for testing

The rail surface roughness becomes visible after the rail sample treatment by sandblasting in the laboratory (Fig. 8, left). The device for EC testing detects roughness that cannot be detected by visual inspection (Fig. 8, right). EC testing of surface and subsurface defects that cannot be detected by visual inspection is shown in Fig. 9. This proves the importance of grinding of new rails and cyclic grinding.

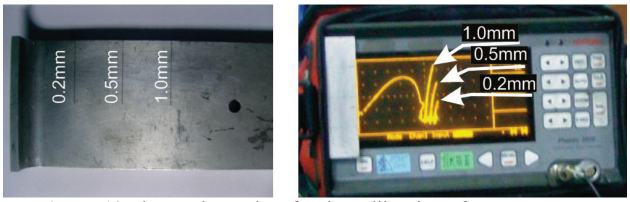

Figure 10 The steel template for the calibration of measurements

For calibration of EC signals the steel template with known crack depths (0,2 mm, 0,5 mm and 1,0 mm) was used (Fig. 10). EC signal amplitude depends only on the depth of the crack and EC signal can determine depth of the defect only approximately since the template steel and rail steel cannot have the same mechanical and electrical quality, homogeneity, roughness etc. Same signal gain (sensitivity) could not be used for the determination of different depth of defect sizes (Fig. 2, right). However, the amplitude is dependent of the crack spatial position on rail gauge, but independent of the crack spatial orientation.

4 Discussion

In the last decades, Serbian railway operator did not plan enough resources for maintenance. The result is extremely bad conditions of railway infrastructure. Superposition of track geometry irregularities disturbs an optimal geometry and increases stresses in the wheel-rail contact. On such track sections the increase of RCF in rail steel can be identified. With increasing rail hardness the wear of rail head is reduced and the time needed to adjust rail head to the wheel shape is prolonged. This explains the occurrence of dangerous HC defects on the rails with quality 900 just two years after their laying into track. With increasing rail hardness the spacing between the HC cracks is reduced and risk of the spalling on the gauge corner is increased.

This phenomenon is not only related to rail steel quality but to rail manufacturer. In addition to PZH rails made by the Chinese producer PZC Steel (treated in this paper), similar problems occur with rail quality 900 manufactured by Donawitz, while rails made by other manufacturers did not show susceptibility to cracking and sudden changes on the driving surface [20, 22].

Quite expected, severe HC phenomenon due to high accumulated traffic loads (rails are 40 or more years in service) was observed on the rail steel grade 700. Besides, causes of the HC defects are worn out elements of track superstructure and irregularities of track geometry.

The visual inspection should be improved by using the fluorescent penetrates, especially under poor seeing conditions in tunnels, but rail surface needs to be clean. Unfortunately, in most cases the head surface is contaminated by lubricant. Lubrication of the outer rail in curves reduces lateral wear of rail, but it leads to HC development. Hence, the authors suggest obligatory application of grinding strategy against HC defects.

The visual inspection on Serbian railways shows progressive development of HC defects due to the penetration of lubricant mixed with impurities and water in the fissures on gauge corner. Also, lubricants have a negative influence on visual inspection (especially in tunnels because of reduced visibility) and disable the use of penetrates [12].

EC inspection provides detection of subsurface cracks (which are not observed by visual inspection), and surface roughness (which is not visually observed before treatment by sandblasting). Nevertheless, EC inspection cannot determine depth of the defect exactly. Depth of defect can be calculated indirectly by measuring the fissure depth and angle α of progression (Fig. 2), or by installing the EC device in rail grinding trains [23, 24]. It is not possible to measure the angle by using the EC method. Based on a long period of investigation, for calculation of HC defect depth one should use large range of the angle values: from 15° to 30°. This is a serious disadvantage of EC testing, because depth of defect can only be measured indirectly [4, 24]. Therefore, the categorisation of HC defects by size and activities in accordance with UIC Code 725 (Tab. 4) cannot be applied in practice.

5 Conclusion

This research has indicated the occurrence of severe HC defects in conditions of irregular track geometry. Also, it is found out that the HC defect is not a phenomenon which is characteristic only for high speed and heavy haul railways.

Unfortunately, the HC defects are not included in [26], which is still officially in use in Serbian Railways. Synchronizing [26] with the UIC Codes [4] and [9] 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. The objective is exchange of experience and development of unique methodologies of infrastructure maintenance managing, on the European level and further. The realization of interoperability of European railway network demands that every infrastructure manager has a maintenance plan for each conventional line for the infrastructure subsystem [25]. This plan should include inspection and strategy against HC defects. Maintenance strategy should provide extra rail service life and should reduce overall rail maintenance costs. Rail is a very expensive component of the track and any extension of rail life has an economic significance. Every infrastructure manager needs to adjust maintenance strategy to local conditions in order to improve traffic safety. An important part of this strategy is taking measures against rail rolling contact fatigue. The effective measures affect controllable features, for example, wheel-rail forces, the size, geometry and location of the wheel-rail contact patch, friction forces, lubrication, residual, bending and thermal stresses.

It is very important to detect rail defects in a track as early as possible. The conducted experiment in the Laboratory JAT in Belgrade has shown that the depth of HC defect cannot be exactly determined using the eddy current method. This means that the recommended actions in accordance with [9] are unusable in practice. Optimal detection method should provide reliable data on measured length, depth and spatial position of HC fissure on track rail. This kind of method for non-destructive testing of rail in service does not exist so far. In praxis, it is important to combine several detection methods in order to increase possibility of early detection of the defect: visual inspection, ultrasound testing and eddy current testing. To reduce the probability that some defects remain undetected, the authors recommend the use of video recordings [27].

Therefore, it is important to apply the grinding strategies against HC defects as follows: preventive activities ("rail care"), corrective activities (the removal of more or less severe defects), and cyclical (controlled) activities during the whole rail service life [28].

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