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The Importance of Rail Inspections in the Urban Area -Aspect of Head Checking Rail Defects

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Abstract

Control of railway noise is very significant part of the urban traffic policy. An increase of railway noise could significantly reduce the quality of life of citizens. This paper analyzes and suggests necessary measures for managing railway noise and traffic safety by rail inspection and grinding. It considers and suggests inspection methods for early detection of head checking (HC) rail defects. Otherwise, HC defects could lead to rail cracks and breakages that might endanger the traffic safety. In addition, this paper examines the real limits of non-destructive methods for detecting HC defects in track in service. Combining several non-destructive inspection methods and rail grinding are recommended for efficient railway noise control in the urban area.

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Keywords: urban area, urban civil engineering, railway, head checking, rail inspection

1. Introduction

Interdependence The railway noise significantly reduces the life quality in the urban area (Fig. 1). Enhanced noise causes firstly uneasiness, then irritability, tendency towards depression, insomnia, digestive problems, even cardio-vascular diseases and deafness. Therefore, utilization of methodical measures for noise reduction is expected from the railway managers, civil engineers [1, 2, 4] and transport operators.

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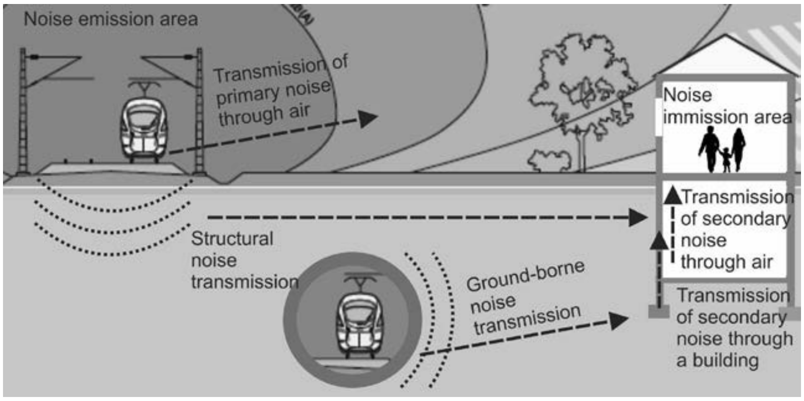


Fig. 1. The principle of railway noise transmission to the surrounding objects

By analyzing the structure of noise emission (Fig. 2), it can be concluded that noise in the wheel/rail contact is the major problem in the widest speed range. Therefore, the condition of rail head surface is very important.It is influenced by subgrade condition [5, 6], substructure condition [6-11], track geometry [12] and vehicle condition. This research only deals with the condition of rail head surface that is the result of the appearance of rail defects due the rolling contact fatigue (RCF).

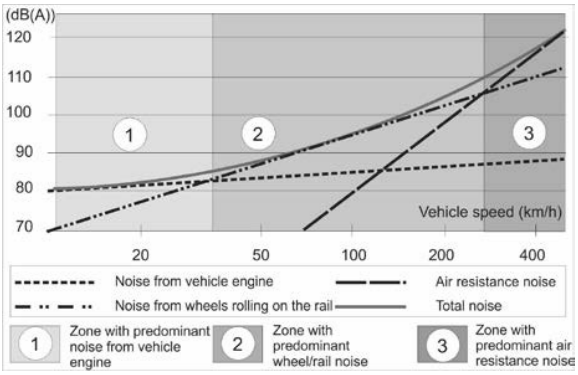


Fig. 2. Levels and sources of railway noise depending on the vehicle speed

Corrugation of the upper surface of the rail head is the most frequent cause of the rail head roughness and wheel/rail noise. The phenomenon is observed as a periodical sequence of bright ridges and dark hollows on the running surface. In addition, a common cause of the roughness of rail head surface are defects caused by the rail RCF phenomenon. The major occurrence of the RCF rail defects are head checkings (HC) and squats around the globe [13-18].

Since 1987 the complex RCF phenomenon has been the subject of a research programme of the European Rail Research Institute [15] which has contributed to a better understanding of the phenomenon and established a uniform terminology in the UIC Rail Defect Catalogue [19]. In accordance with [15], terms "head checking" and "squat" rail defects are officially used in all world languages in scientific and technical literature without translation in order to avoid existing confusion in terminology and misunderstandings. Finally, the Handbook of rail defects [19] includes "head checking" and "squat" as types of rail defects due to rolling contact fatigue (Fig. 3). Experimental research of the influence of rail steel grade on wear and RCF showed that it is possible to reduce RCF and wear by using higher steel grades [14, 20, 21]. On the other hand, studies have shown the importance of wear for producing thin metallic flakes and removing surface micro-cracks [22].

Fig.3. Head checking (left) and squat rail defect (right) caused by rolling contact fatigue (photos taken on the Belgrade Centre – New Belgrade section)

This paper shows the effectiveness of different inspection methods for detection of HC rail defects. It points out the importance of early detection of HC rail defects for traffic safety and life cycle costs of rails.

2. Head Checking Rail Defect duethe Rolling Contact Fatigue

Rolling contact fatigue (RCF) is a process of gradual destruction due the creation and development of an initial crack. This process could lead to the rail breaks under the influence of variable traffic and axle load, which is transferred to the rail head over small wheel/rail contact surface (Fig. 4). The area of wheel/rail contact surface usually ranges from 1.5 to 3.0 cm2, or up to 5.0 cm2 in case of worn or defective wheels and/or rails.

Generally, a fracture surface due to RCF is recognizable by two visually different areas: fatigue area and rail break area (Fig. 5). The fatigue area is smooth and dark, and it can be distinguished by the increase of fatigue crack. Fatigue area occurs on the places of increased stress concentration due the geometry and constructive characteristics of the rail profile, surface damages, method of rail production, exploitation damages, etc.

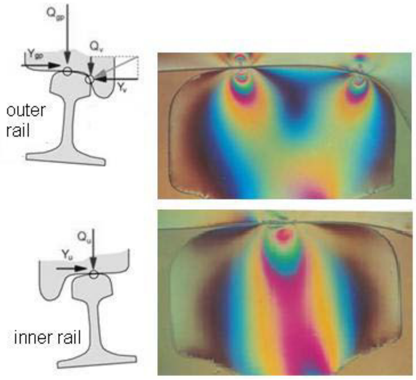


Fig. 4. The wheel/rail contact in a curve on the outer and inner rail

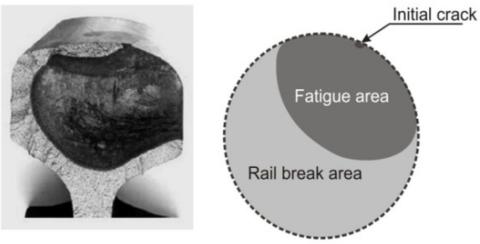


Fig. 5. Characteristic look of a steel surface after break caused by rolling contact fatigue

As a part of the research project [23], the sensitivity analysis was performed to demonstrate how different traffic and track conditions affect a crack growth rate (Fig. 6). Crack growth depends on many factors, and the most important are: static wheel load, dynamic wheel load, vehicle rolling characteristics, rail profile, rail steel, temperature differential, residual rail stress, rail head wear, track geometry, track stiffness. A crack will have a certain detectable size, which depends on the used detection technique. The propagation of the crack from initial state can be followed until it reaches the critical size. Further crack propagation can lead to the rail break. The passed 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 each defect type, crack growth rate can vary considerably. However, simple crack growth models can be created just for transversal defects in the rail head area [24].

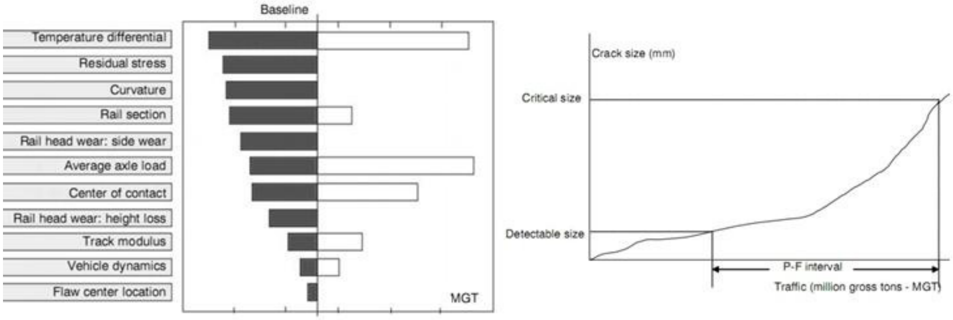


Fig. 6. One example of the influence of various factors on crack growth rate (left) and definition of the P-F interval (right) [23]

The HC rail defect appears in general on the outer rail (gauge shoulder and gauge corner) in the curves with radius up to 3,000 m, but most frequently in the curves with the radius of up to 1,500 m (Fig. 7).

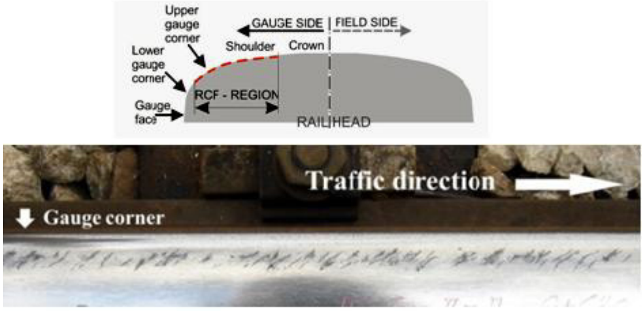


Fig. 7. The characteristic RCF region on the rail head [17,18,25]

Defect is distinguished on tracks with a defined traffic direction (for example, on double track line). In accordance with [19], the code number for HC defect is 2223 (Fig. 8).

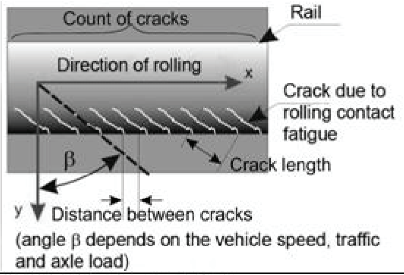
Position of digit in the code:		The meaning of digit in the code:	
1st digit	2	Defect zone away from rail ends	
2nd digit	2	Surface of rail head	
3rd digit	2	Shelling	
4th digit	3	Fissuring and/or scaling at the gauge corner	
Code:	2223 - Head checking/Fissuring/Scaling at the gauge corner		

Fig. 8. The principle of coding for HC rail defect according to [19] and typical orientation of HC fissures on the rail head

The HC defect is caused by lateral contact force and geometrical spin [25]. It occurs just below the upper surface of the rail head (≤ 0.1 mm), progresses rapidly upwards and reaches the upper surface of rail head. Due the influence of traffic load, the cracks can be directed downward with the risk of multiple rail fractures. The HC defect appears as fine, short, raked, surface fissures at more or less regular distance, which usually ranges from 1 to 7 mm (and up to few centimeters, depending on the rail steel quality). Surface fissures indicate that fissures already exist below the surface, extending to certain depth and in certain direction inside the rail head. By increasing rail hardness, the spacing between the cracks is reduced. It is especially dangerous when cracks propagate in low acute angles of approximately 15° into the rail head and the crack distance is reduced to 0.5 mm. In this case multiple rail fractures may occur, which always leads to train derailment.

Many studies have been carried out in order to determine the relationship between HC occurrences and contact geometry [13,25-27]. HC occurrences are more distinct on railways without adequate maintenance strategy. The standard life cycle of rails can be reduced to only 2-3 years, if adequate maintenance measures against HC defects are not taken in time [27,28].

Well known traffic accident happened in Hatfield on October 17th 2001. This accident was caused by the rail breaks due to the numerous HC cracks [27]. EU began with intense safety inspections after this disaster. Special attention is drawn on HC and squat rail defects.

3. Detection of the HC Rail Defect in Track

Active An optimal detection method for HC rail defects should provide early detection of rail damage and reliable data about measured length, depth and spatial position of fissures in rail head. This kind of method for non-destructive testing of track rail does not exist so far. In praxis, several detection methods are combined in order to increase possibility of early detection of the defect.

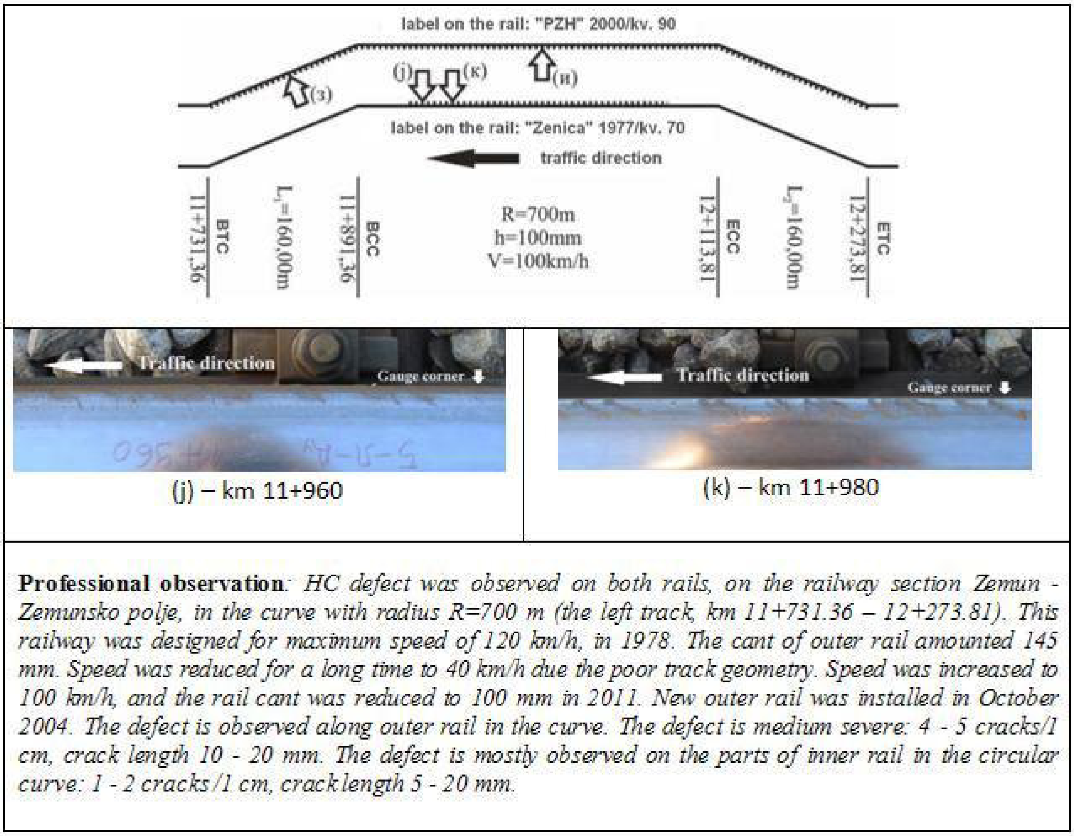
Professional literature [17, 18, 24, 25, 28] recommends the visual inspection, optical system by camera, ultrasonic testing using vehicle, and manual check with ultrasonic testing, as well as eddy current (EC) testing.

Visual Inspection. Rail network should be inspected visually twice a year (every six months), with the help of photographs and video images. This method takes a huge number of man-hours and includes the subjectivity. It is recommended for sections with 50 m length, which are classified with respect to the maximum crack length (Fig. 5). Pieces of information about RCF defects, which were observed during the visual inspection, are entered in the form in accordance with [19] and saved in a database. The other necessary details and photos of RCF defect are attached to the form (Fig. 9).

During inspection of HC defects, special attention should be drawn to the outer rail in curves: usually in curves with radius R ≤ 3,000 m, and most often in curves with radius R ≤ 1,500 m. In the same way, attention should be drawn to the spalling due the small distance between the HC cracks on the gauge corner. By increasing the rail steel hardness, wear of the rail head is reduced and the time required to adjust rail head to the wheel shape is prolonged.

In addition, spacing between the HC cracks may be reduced and risk of the spalling on the gauge corner could increase.

Besides that, rail switches, rail weld zones, expansion joints and sections with irregular track geometry should also be visually investigated with particular attention.



(j) – km 11+960

(k) – km 11+980

Professional observation: *HC defect was observed on both rails, 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 railway was designed for maximum speed of 120 km/h, in 1978. The cant of outer rail amounted 145 mm. Speed was reduced for a long time to 40 km/h due the 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 10 - 20 mm. The defect is mostly observed on the parts of inner rail in the circular curve: 1 - 2 cracks/1 cm, crack length 5 - 20 mm.*

Fig. 9. An example form with the sketch, photographs and professional observation on the Serbian Railways

Tunnels usually have poor visibility due the lack of day light. In such circumstances, the surface of rail head should be illuminated by a light source. The visual inspection could be improved using the fluorescent penetrants, 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 might lead to the HC fissure propagation due the penetration of lubricant mixed with impurities and water in the fissures on gauge corner of rail (Fig. 10).

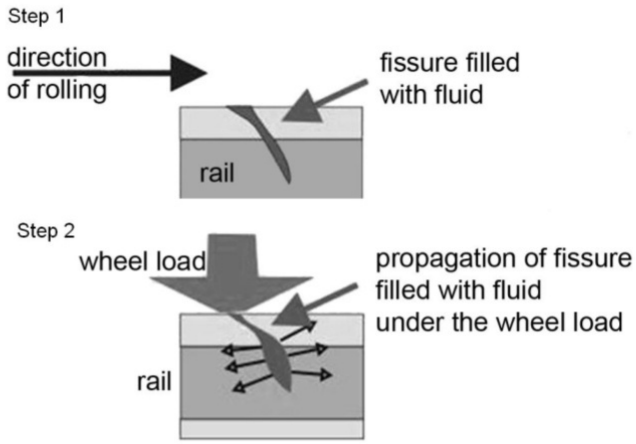


Fig. 10. The process of HC fissure propagation due the lubricant penetration

Visually observed HC defects are classified according to the crack length on the rail head surface (Fig. 8). The rail sections with 50 m length are classified with respect to the maximum crack length according to Table 1 [17,25].

Table 1. The severity classification of HC defect

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

Fig. 11 shows the categorization of HC rail defect in accordance with UIC Code 725 [24]. The size of HC defect cannot be determined by visual inspection. In addition to visual inspection, UIC Code 725 [24] proposes ultrasonic inspection (using vehicle mounted equipment or manual equipment).

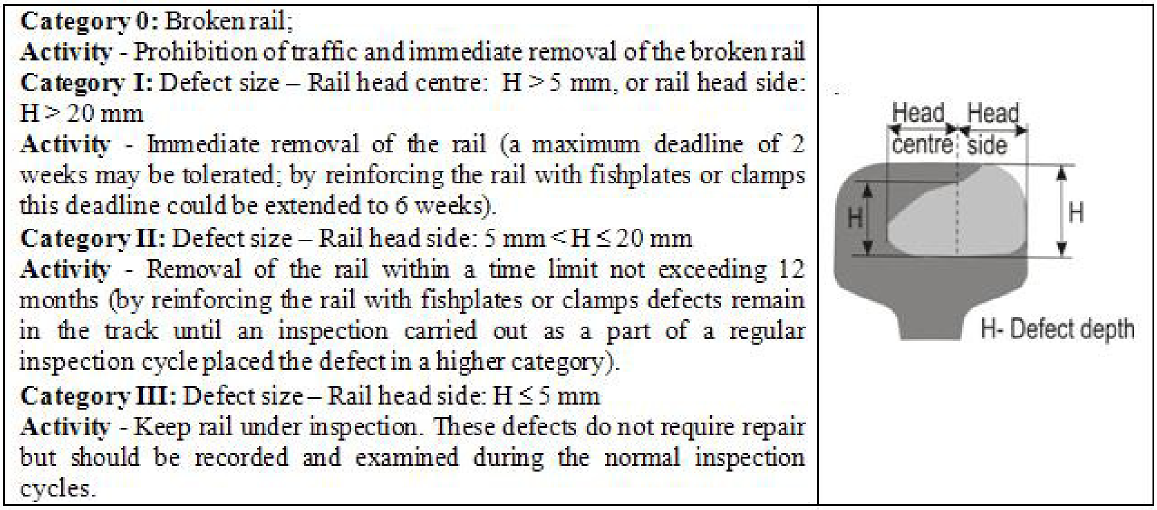

Category 0: Broken rail;
Activity - Prohibition of traffic and immediate removal of the broken rail
Category I: Defect size – Rail head centre: H > 5 mm, or rail head side: H > 20 mm
Activity - Immediate removal of the rail (a maximum deadline of 2 weeks may be tolerated; by reinforcing the rail with fishplates or clamps this deadline could be extended to 6 weeks).
Category II: Defect size – Rail head side: 5 mm < H ≤ 20 mm
Activity - Removal of the rail within a time limit not exceeding 12 months (by reinforcing the rail with fishplates or clamps 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 ≤ 5 mm
Activity - Keep rail under inspection. These defects do not require repair but should be recorded and examined during the normal inspection cycles.

Fig. 11. Categories of HC defects by size in accordance with [24]

Pieces of information about HC defects, which were observed during the visual inspection, are entered in the main form shown in Table 2 and saved in a database.

Table 2. An example of completed main form

1. General information: **Type of defect :** *HC defect* **(Code number: 2223)**				
Damaged rail ■	Cracked rail ☐		Broken rail ☐	
2. Precise location of the defect in the track and date:				
Line: *Beograd - Bar*				
Section:	from km 12 + 000to km 12 + 500			
Track:	Left track ☐	Right track ☐	One track ■	
Rail:	Left rail ☐	Right rail■		
Kilometre point	From km 12+ 403 to km 12+ 434			
Date the defect was discovered: 20.12.2014	Date the defect was repaired:	Date the broken rail was removed:		
3Detection 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= *70 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: *K*	Type: rigid	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 +
At the rail ends ☐			Away from the rail ends ■	
Type of joint :	rail joint with fishplate ☐	welded joint ☐	insulated ☐	glued and 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: *120 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)		
7.Action taken				
Keep rail under inspection ■	Rail removed on:	Rail despatched to:		

In addition, the authors recommend visual inspection improvement by using video recordings and the software that analyses them, thus identifying the defect on the rail head. The proposed improvement of visual inspection is a part of an ongoing research project [29]. This software creates a series of images from video, and then analyses each image for possible defect. In order to achieve this, software includes algorithm that can recognize defect pattern. When the pattern is recognized, station is calculated and linked with the image. Therefore, final software results are stations and images of possible rail defects. Afterwards, user can check the results and remove wrongly analysed images.

3.1. Ultrasonic Inspection

Nowadays, ultrasonic testing is a standard method on railways around the globe. It has become the most commonly used rail testing method implemented in inspection cars. New generation of inspection cars can operate at speeds up to 100 km/h. Unfortunately, ultrasonic testing method has very high percentage of rail defect indication which is proven false after manual test verification.

This method is not applicable for inspection of surface fissures at small distance and at low acute angle towards the upper rail head surface. Also, the method does not provide precise measures in the narrow zone of rail gauge corner. Combination of ultrasonic inspection (US) and eddy current (EC) inspection improves probability of early detection of RCF defect. This is the way to discover the most, but not all RCF defects.

Fig. 12 shows the condition when some of the deeper HC cracks are undetected due the limitation of the ultrasonic inspection method.

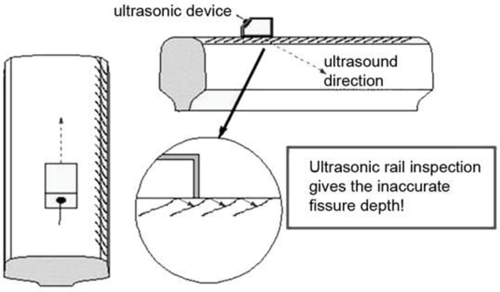


Fig. 12. Unreliable HC fissures depth measurement with the usual ultrasonic inspection procedure [30]

3.2. Eddy Current Inspection.

The procedure of EC testing is based on the electromagnetic interaction between the magnetic field of a test probe and the currents induced in the metallic material. The EC field variations are caused by inhomogeneity of the rail steel surface and subsurface. These variations are used to estimate size and depth of the crack. Defect depth can be calculated indirectly by measuring the crack depth and angle α of the crack progression (Fig. 13), or by installing the EC device in the rail grinding train. It is not possible to measure the angle α by using the EC method. According to the long period of investigation, calculation of HC defect depth can be performed using wide range of angle values, from 15° to 30°. This is the serious disadvantage of EC inspection method, because depth of defect can only be measured indirectly [30].

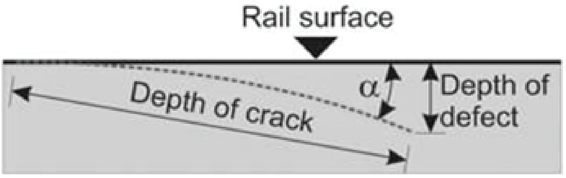


Fig. 13. Depth of HC crack and depth of defect

The advantages of EC rail inspection are: early detection of the initial fissures (depth 0.2 mm), detection of fissures below the rail head surface, portability of testing device, no use of consumable materials, instant reading of measuring results, possible integration of device in the recording cars and rail grinding trains.

Fig. 14 shows the vehicle equipped with eight-channel device for rail testing using the eddy current: four sensors on the left and four sensors on the right rail [31].

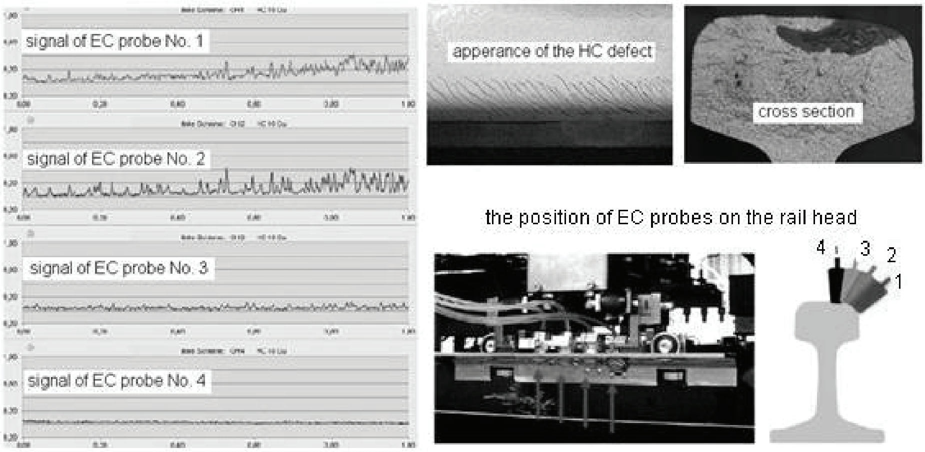


Fig. 14. The position of EC probes on the rail head and characteristic signals on the rail gauge corner with HC defects [31]

Modern rail management involves preventive, cyclic and corrective rail grinding against HC defects in the rail maintenance plan. Due the many insufficiently explored influential factors (static wheel load, dynamic wheel load, vehicle rolling characteristics, rail profile, rail steel, temperature differential, residual rail stress, rail head wear, track geometry, track stiffness) growth of HC cracks cannot be exactly predicted [23,32]. Based on practical experience, exponential growth of HC defect is presumed, depending on accumulated gross ton traffic load (in MGT) in each specific case. Fig. 15 shows vertical wear and estimated exponential progression of HC rail defects with cyclic grinding of rail head, as well as various impacts on the quality state during the rail service life span.

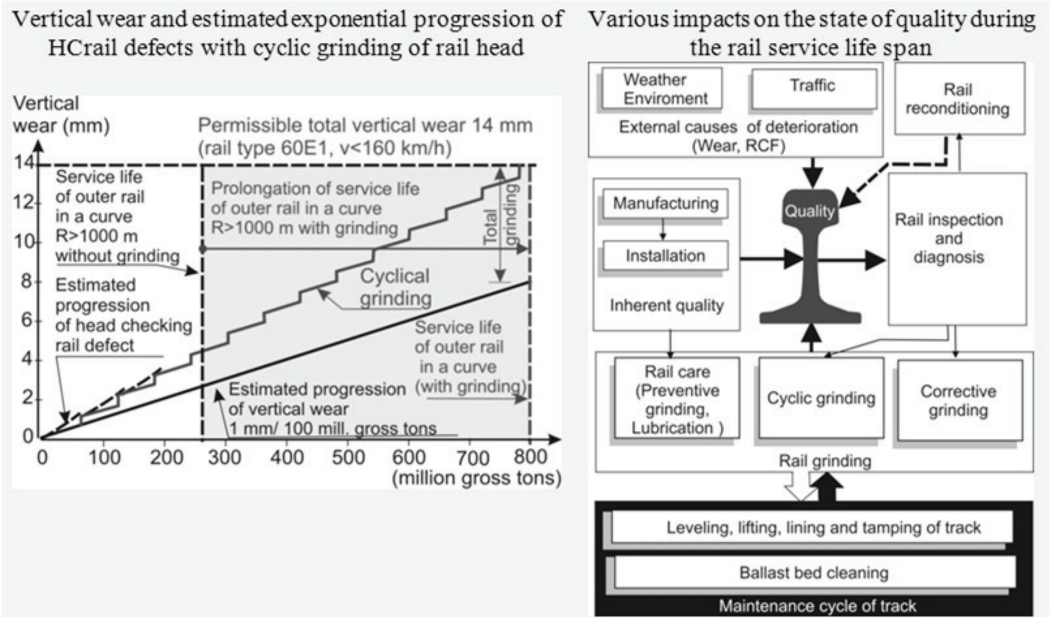


Fig. 15. Prolongation of rail service life using grinding [32]

EC inspection of rail head is applied after each passage of grinding vehicle. Thus, EC inspection indicates the necessity of next grinding operation.

4. Summary

Rail traffic noise is the big challenge for urban planners, civil engineers and environmental engineers since the most important task iscontrollingthe traffic noise in cities. Modern rail maintenance strategy should provide noise control and safe traffic in the urban area at all times. The policy of modern railway development assumes control of the possible harmful influences on the urban area in the phases of planning, design, construction and maintenance of the railway infrastructure. Regarding the great importance of residents health, education of civil engineers must include application of measures for noise reduction in the urban area [33-38].

The main research topic in this paper is rail maintenance strategy for noise control. Rail inspection is an essential part of maintenance. It is very important to detect rail defects in a track as early as possible. An 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. In addition, it is important to update the database about the RCF rail defects and implement an appropriate grinding strategy.

Today, grinding (along with lubrication of outer rail in curve) is a part of the routine rail-careand very efficient method to control noise emission in the urban area. The grinding of surface roughness prevents its further development. The grinding effect is not permanent, because corrugation reoccurs after some time. It is considered that the noise decrease potential, based on the rail-care, is from 15 to 20 dB(A) comparing to the track condition without rail-care.

Further, should provide an additional rail service life and reduce overall rail maintenance costs. Rail is very expensive component of the track (more than 30 % for ballasted track and about 20 % for slab track [32]) and any extension of rail service life has economic significance. Each 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 dangerous rail rolling contact fatigue.

Acknowledgement

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