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MANAGING RAIL SERVICE LIFE

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The service life of rails depends especially on the operational loads and speeds on the railway lines, as well as on the rail maintenance policy. There are multiple aspects of rail maintenance optimization. The following article considers optimisation of rail maintenance activities relating to rail head surface condition in order to reduce corrective work on track geometry, as well as to minimize the overall costs for track maintenance. The objects of this research are issues and challenges related to rail and track maintenance in curves on modern conventional railway lines for mixed traffic.

Key words: rail, life cycle, management, track, maintenance

INTRODUCTION

Rails are the track components which account for a large proportion of the cost of new railway infrastructure, ≥30 % for ballasted track and 20 % for slab track. In this sense, rail management plays a key role in the optimization of track costs including the costs of track maintenance. Rail management includes optimal choice of rail (the rail profile, and the grade and structure of the steel used), in-situ rail inspection, lubrication, grinding, rail repair, rail renewal and/or rail reconditioning.

Also, the service life of concrete sleepers is much longer than that of the rails in highly loaded tracks. Particularly in curves with small radius, the life of the inner rail is greatly reduced due to defects type 2202 [1] and lateral wear.

On the other hand, in curves with radius $R \leq 3\ 000$ m, and the most often with $R \leq 1\ 500$ m, the life of the outer rail is greatly reduced due to defects type 2223 [1].

Rail cost considerations are not new, but the consideration of life cycle costs was, however, rare. With the help of the life-cycle cost analysis it is possible to make an accurate and transparent decision on material selection, preventive and corrective maintenance strategy and renewal schedule.

This paper shows the possibility of reducing the maintenance costs by using the "integrated approach" to track maintenance on modern conventional railway lines for mixed traffic. An integrated maintenance considers the possibility of simultaneous replacement of both rails and sleepers, as well as harmonization of rail grinding schedule with the terms of maintenance cycle of track (tamping and ballast cleaning) in the railway section that is as long as possible.

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RAIL SERVICE LIFE

The rail service life depends on several factors. It depends particularly on the cumulative operating load, axle load and vehicle conditions, the level and structure of vehicle speeds, rail quality and rail profile, the track quality, the position on the railway line (curve, straight track, inclination), rail maintenance and the treatment during the transportation and installation. An inadequate rail maintenance strategy decreases the rail service life due to shortened renewal cycle.

Managing the flows of process is an important part of logistics, dating back to the 600 BC, i.e. to the ancient times [2].

On the modern railway lines for mixed traffic, radii of curves are defined based on the speed of the fastest passenger train. In such circumstances ($R_{min} \geq 1\ 000$ m), rail wear, rolling contact fatigue and plastic flow are major contributors of rail deterioration depending on the operational conditions. However, rails have been usually removed and replaced due to rail defects. Nowadays, rails are rarely replaced due to spending of wear reserve.

Modern rail management necessarily involves preventive rail grinding. It must be a standard activity of the rail maintenance plan. Aim of preventive grinding is to provide optimal conditions in wheel-rail contact at the beginning of exploitation, to remove usual irregularities that appeared during rail installation and track laying, to reduce rail noise and future development of rail surface defects. The preventive rail grinding is maintenance activity that must be carried out without exception.

High degree of wear leads to the premature wheel and vehicle damage, affecting its stability and creating unacceptable safety breaches [3].

In practice, the rail service life of the outer rail in curves (300 m $\leq R \leq$ 3 000 m) is limited by head checking (HC) rail defect (rail defect type 2223 in accordance with [1]). Also, the rail service life of the inner rail in curves is limited by long-pitch corrugation (rail defect type 2202 in accordance with [1]). This means that the theoretical rail service life will not be used entirely. The question is whether an effective maintenance strategy against rail defects can provide extension of rail service life in a curve. The answer will be asked through examples of rail management in a curve.

1 Example No. 1 - Outer rail in a curve

The research was 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 this railway lines is D4. Both are double track lines for mixed traffic. HC rail defects were found on expected places: outer rail in curves $R \geq 600$ m. Typical RCF region was observed in the outer rail, on the gauge side and in the gauge corner [4, 5].

The possibility of prolongation of service life of outer rail in a curve $R > 1\,000$ m was considered. It was assumed that the side wear of outer rail can be neglected in this consideration.

Due to the many insufficiently explored influential factors it cannot be exactly predicted growth of HC cracks. Based on practical experience, it is presumed exponential growth of HC defect depending on accumulated traffic load.

Figure 1 shows the theoretical service life of the outer rail without rail grinding in a curve with a radius $R > 1\,000$ m. Consideration was based on the estimated linear progression of vertical wear 1 mm/100 mill. gross tons, side wear 0 mm and permissible max. vertical wear 14 mm for rail type 60E1 and speed $v < 160$ km/h. By the presumed exponential growth of HC defect without grinding, the real service lifespan was multiple shorter due to possible rail failure.

Exponential growth of HC rail crack was expressed as an increase in defect size per accumulated gross ton traffic load (million gross tons – MGT). Crack growth depends on many factors where the most important are [6]: 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.

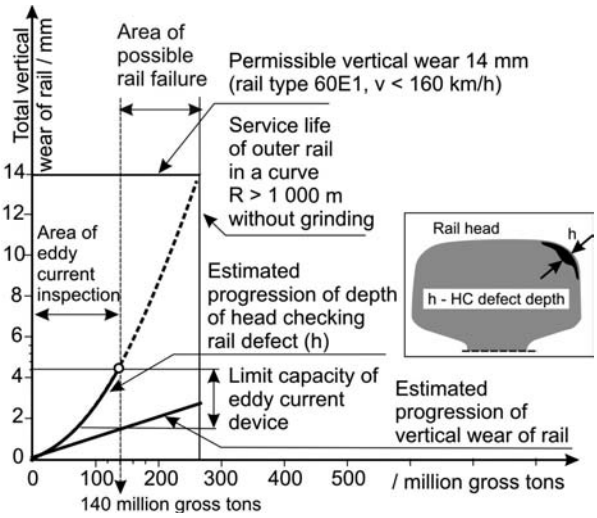

Figure 1 Exponential model for prediction of progression of HC defects and linear model of vertical wear

HC crack should have a certain detectable size which depends on the detection technique used. The eddy current inspection of rails provides early detection of the initial fissures and detection of fissures below the rail head surface. In Figure 1, length of the area of possible uncontrollable rail failure depends on the capacity of eddy current device for rail inspection [5]. The capacity of the eddy current device defines the maximum controlled depth of the HC defect.

Figure 1 shows detectable size of HC defect 2,7 mm (the most common capacity of EC device for rail inspection). In such circumstances, allowed depth of crack can be reached after 140 million gross tons (without rail grinding). This corresponds to 7 years of exploitation on typical main line with annual traffic load of 20 million gross tons [6-8]. These considerations are a direct consequence of the adopted function of defect growth and cannot be used in the general case. It cannot be exactly predicted growth of HC cracks in the general case. Infrastructure manager has to develop a appropriate model of growth of HC defects for each characteristic section.

Figure 2 shows one variant of cyclic grinding with the interval 60 million gross tons and rail service lifespan 800 mill. gross tons. If the traffic load on the railway line is 20 mill. gross tons per year, then service lifespan of outer rail in a curve is equal to service lifespan of concrete sleepers: 800 mill. gross tons / 20 mill. gross tons per year = 40 years. In this sense, the grinding cycle amounts 60 million gross tons / 20 mill. gross tons per year = 3 years. Also, cyclical grinding of outer rail in a curve might provide simultaneous replacement of both rails (inner and outer rail in a curve) and concrete sleepers.

In this way, rail grinding is a part of an integrated maintenance strategy that allows the simultaneous replacement of rails and sleepers. The next level of consideration is harmonization of the terms of cyclical grinding of rail with the terms of maintenance cycle of track. In that sense, the best solution is the application of rail grinding activities immediately after track maintenance cycles: ballast bed cleaning (typical cycle 150 – 300 MGT) and tamping of track with leveling and lining (typical cycle 40 – 70 MGT). This ensures that the "ideal" track geometry is restored and that total life cycle costs of the track are minimized.

2 Example No. 2 - Inner rail in a curve

Long-pitch corrugation generally occurs on the inside stretches of curves and affects the service life of inner rails. However, the long pitch corrugations can sometimes occur on the high rails of curves and sometimes on both. This is mainly a function of the inappropriate superelevation of the rail, which may lead to the higher load on one rail comparing to other. This should be taken into account by the Infrastructure Manager when reduced speeds are prescribed on the railway section.

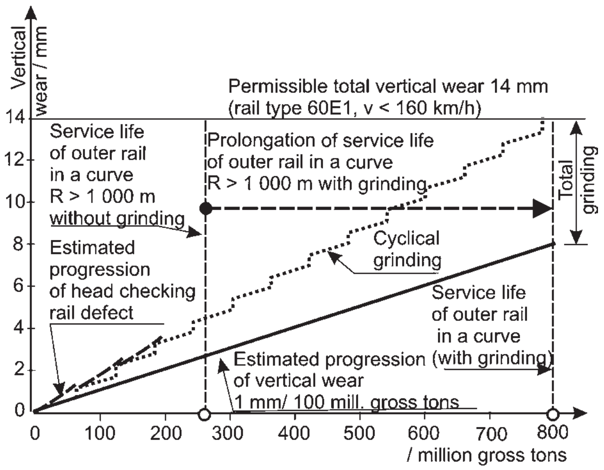

Figure 2 Progression of rail defects HC and vertical wear with grinding of rail

Figure 3 shows an irregular surface of rail head with defect type 2202 and the sinusoidal model of longitudinal shape of this rail defect.

Long-pitch corrugation significantly shortens the lifespan of inner rails. In this case a vertical wear of rail due to grinding is not crucial. Vertical acceleration of unsprung mass per wheel produce additional dynamic stress and contributes to deterioration of track geometry. The increase of ballast pressure results in decrease of maintenance cycle. This phenomenon is more pronounced on the lines for heavy and mixed traffic.

Formula (1) represents the exponential model of deterioration of track geometry quality:

$$\gamma = \frac{N_{ref}}{N_p} = \left[\frac{\sigma_p}{\sigma_{ref}}\right]^w \tag{1}$$

Table 1 shows a shortening of track maintenance cycle 100/γ in accordance with formula (1) on railway lines for mixed traffic ($w = 4$).

Table 1 **Shortening of maintenance cycle**

σ_p/σ_{ref}	γ	100/γ / %
1,1	1,4641	68,30
1,2	2,0736	48,23
1,3	2,8561	35,01
1,4	3,8416	26,03

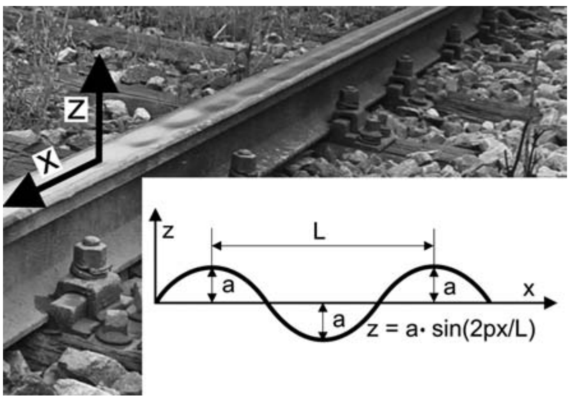

Figure 3 Sinusoidal model of longitudinal shape of rail defect type 2202

The presumptions that were made in this example are: a linear increase of rail defect 2202 depending on the increase of traffic load in the calculation model (eg. 0,02 mm / 10 mil. gross tons [6]), the grinding cycle 60 million gross tons and speed 80 km/h. Unsprung mass per wheel receives the following maximal vertical acceleration (vehicle speed 80 km/h, amplitude of the defect 0,12 mm, wavelength of the defect 30 cm):

$$\ddot{z}_{max} = a \cdot \left(\frac{2\pi}{L} \cdot v\right)^2 \approx 26\ m/\sec^2 \tag{2}$$

The German Railway's dynamic model for the superstructure dimensioning (developed by Professor Eisenmann) takes into account the dependence of the vertical forces from the track quality. The maximum forces Q_{max} are calculated according to statistical analysis, taking into account speed and track geometry:

$$Q_{max} = Q_m \cdot (1 + t \cdot n \cdot \varphi) \tag{3}$$

According to Table 2, for speed 80 km/h, excellent track quality and statistical confidence 67 %, increase of force per wheel with respect to formula (3) amounts:

$$1 + t \cdot s = 1 + 0{,}1 \cdot 1 \cdot (1 + 20/140) = 1{,}114$$

If unsprung mass is 15 %, and vertical acceleration is 26 m/sec^2, then quasi-static axle load is increased by 40 %:

$$Q_{max} = 1{,}114 \cdot Q_m \cdot (\frac{0{,}15 \cdot 26}{9{,}81} + 0{,}85) = 1{,}4 \cdot Q_m \tag{4}$$

On the lines for mixed traffic, the maintenance cycle is only 26,03 % of the reference maintenance cycle if the ballast pressure increases at increments of 40 percent (highlighted row in Table 1). Also, vertical acceleration of unsprung mass per wheel increases ballast pressure and shortens maintenance cycle of track.

Grinding reduces the amplitude of the defect. In this way, cyclic grinding of inner rail in a curve extend the cycle of track maintenance.

Table 2 **The values of parameters for formula (3)**

n	*T*	*f*
0,1 (excellent) 0,2 (average) 0,3 (bad)	1 (67 %) 2 (96 %) 3 (99,7 %)	1 (v < 60 km/h) 1 + (v – 60)/140 (v > 60 km/h)

CONCLUSIONS

Rail wear, rolling contact fatigue and plastic flow are major contributors of rail deterioration depending on the operational conditions on modern railway lines for mixed traffic and high speed trains [9]. Not all cracks impose derailment risk, but they are the major contributors to rail and track degradation. Fortunately, some of the rail defects are removed by wear and by rail grinding process during initial stages of crack development. The uncontrolled development of rail defects threatens traffic safety and increases the cost of rails maintenance: it may lead to premature removal of rails and complete rail failure. Rail break is the last phase of crack develop-

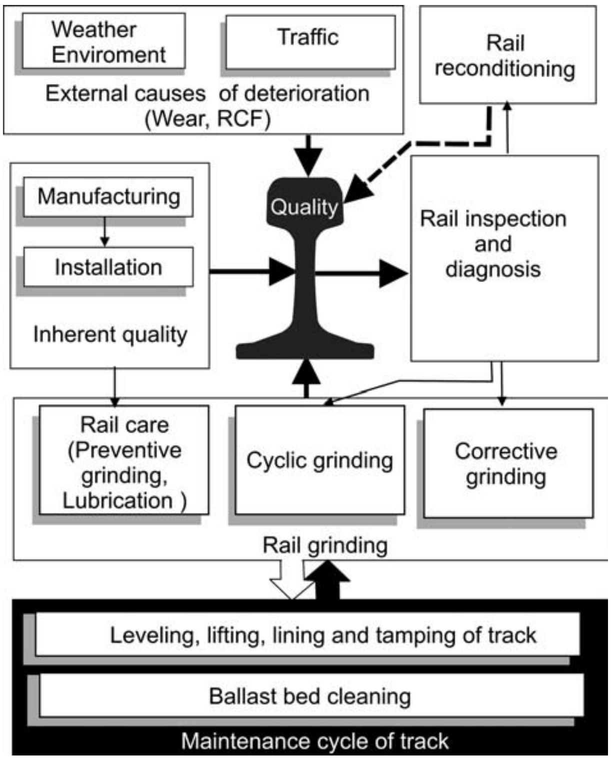

Figure 4 The impacts on the state of quality during the rail service life span

ment process and might lead to catastrophic derailment (including death, injury, costs, loss of public confidence, devastating and long-lasting effects on the industry).

On the other hand, the rail surface defects can produce vibration excitations and the additional dynamic stress. The result is faster deterioration of track geometry. Cyclic grinding removes the surface layer of steel containing the majority of the rail defects and reduces overall rail maintenance costs. Modern strategy of rail grinding includes preventive, cyclic and corrective activities (Figure 4). Rail grinding was presented as a part of an integrated maintenance strategy that allows the simultaneous replacement of rails and sleepers and harmonization rail grinding with maintenance cycle of track (Figure 5).

This paper presents two numerical examples of rail management according to predicted growth of defect types 2223 and 2202. Infrastructure manager has to develop appropriate models of growth of rail defects for each characteristic section. It can be concluded that the best solution is application of rail grinding immediately after track maintenance activities. This ensures the "ideal" track geometry and minimize total life cycle costs of the track.

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NOMENCLATURE

γ	relative factor of settlement,
$100/\gamma$	shortening of maintenance cycle / %,
σ_{ref}	ballast pressure by the reference number of axle crossings / N/cm^2,
σ_p	ballast pressure by the tested number of axle crossings / N/cm^2,
N_{ref}	reference number of axle crossings,
N_p	number of tested axle crossings,
$\ddot{z}_{max}$	maximal vertical acceleration / m/sec^2,
w	an exponent,
v	vehicle speed / km/h,
a	amplitude of the defect / mm,
L	wavelength of the defect / mm,
Q_{max}	quasi-static axle load / kN,
t	statistical confidence,
n	influence of the track quality,
f	influence of speed.

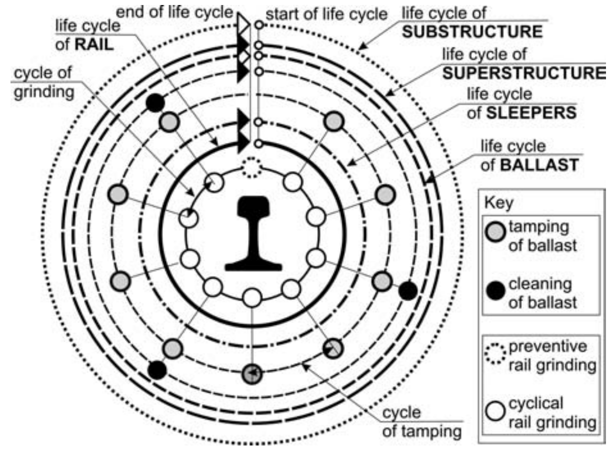

Figure 5 Principles of an integrated track maintenance

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Note: The responsible translator for English language is Luka Lazarević, Belgrade, Serbia