Rolling Contact Fatigue. Application in Rail-Wheel Interaction Modeling

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Abstract: - Rolling contact fatigue is a challenging direction of research with applications in several engineering specializations. A first stage of the research is dedicated to the centers on rail wear and rolling contact fatigue. A second stage will be dedicated to applications in electrical engineering. This paper presents the results of the research of the first stage. Interesting aspects regarding the rolling contact fatigue and centers on rail wear are investigated, integrating these processes and their interactions in order to model the entire life of the rail from installation to final failure. There are also considered the processes that determine the life, such as rail wheel adhesion. Better understanding of these processes and the factors affecting them, will lead to innovative solutions, such as improved coatings, or predictive tools to assist maintenance of the railways, finally reducing costs and increasing the transport capacity.

Key-Words: *rolling, contact, fatigue, wheel, rail, cracks, creep.*

1 Introduction

The last two decades, rail transport has seen a revival by supplying faster, cheaper, more frequent and more reliable connections both in passenger and freight traffic. However, the increased traffic density, higher speeds and higher axle loads which come with this revival, have their specific effects on the wear of railway tracks and thus on the maintenance needs. At the same time, maintenance processes are to be optimized and operating costs reduced.

Given the evolution of the way of exploitation, the rail is subjected to more and higher loads, and thus wear phenomena and fatigue defects appear faster and more frequently. These degradations restrict infrastructure productivity: wear might cause speed limitations or even load restrictions, more frequent inspections andincreasing maintenance costs. In this way, understanding the wear phenomena can lead to improved design of both rolling stock and track, but also to improved inspection, maintenance and renewal policies for existing and future infrastructure. Limited to the rail only, several wear types exist, e.g. shelling, squats, spalling, corrugation, head checks. First, head-checks cracks initiation is analyzed, after which the properties of crack propagation are presented. Afterward, the various way of inspection will be surveyed. Then an overview of the specific techniques of preventives maintenances employed to prevent and control this kind of degradation will be given. Finally curative solutions or more general ways of reducing the occurrence will be presented.

2 Rolling contact fatigue

Rolling contact fatigue is a family of damage phenomena that appear on and in rails due to overstressing of the rail material. This damage may appear first on the surface (e.g. head checks, shelling, and squats) or the subsurface (deep seated shell). In either case, these phenomena are the result of repeated overstressing of the surface or subsurface material by millions of intense wheel-rail contact cycles.

Two key processes influence the rolling contact fatigue - crack initiation and crack propagation. These processes are controlled by a number of factors including environmental conditions, rail and wheel profiles, track curvatures, grades, lubrication practices, rail metallurgy, vehicle characteristics, track geometry errors, and rail grinding practices. They all play a role in the formation of rolling contact fatigue and – universally – can be used to control and minimize rolling contact fatigue.

The amplitude and position of the crack initiating stresses varies depending on the contact geometry, load and friction conditions. Under high friction conditions shear stresses are large but very shallow. Under low friction conditions, the peak shear stress decreases but extends deeper into the railhead. The result is that some rolling contact fatigue defects are initiated at the surface and others below the surface.

3 Various types of rolling contact fatigue defects

Rolling contact fatigue will lead to surface and subsurface cracks as stated earlier. Based on the nature and location of the failures,they are classified as follows.

3.1 Surface Initiated Defects

Head checks - are fine surface cracks resulting from cold working of the metal under contact stress. The slip which occurs between wheel and rail in curves of over 1000 m radius leads to high tangential forces around the gaugecorner of the rail head with high coefficient of friction (>0.3).

This further leads to high surface stresses and, where the rail wear is small,to surface cracks. The head checks appear at a spacing of 1 to 5mm along the rail in the gauge corner of the outer rail in curves. Pieces of metals may break out from between the checks. The transverse cracks on the surface also appear. Beneath the surface cracks, subsurface defects may develop, which are potentially dangerous.

Squats - this defect is common in tracks catering to high speed passenger trains with low axle loads. It is found both in straight and moderately curved track. The first superficial indication of the failure is the appearance of fine surface cracks located at the gauge side of the running band and lying at an angle of 45 degree to the forward direction of traffic in plan view. This is followed by the appearance of dark spot on the running band. The depression will be up to 1.6mm and cause higher dynamic wheel/rail forces.

Such cracks may initiate from a white itching martensitic layer on the surface of the rail due to plastic flow resulted from longitudinal traction of locomotive wheels causing a surface layer of rail material ratchets until crack develops on the center of the railhead on the field side.

3.2Sub-Surface initiated cracks

Shattering Defects - These defects which develop around 10 to 15 mm below the rail head from longitudinal cavities caused by the presence of Hydrogen. These cavities develop under the influence of thermal and residual stresses from roller straightening and cooling processes in the normal rail section during the manufacturing process or at the welds, figure 1.

Fig.1–Rail cracks

To conclude, there are several measures to be undertaken in order to reduce this type of failures in rail and welds:

• improving the rail quality by reduction of hydrogen content in the rail steel;
• reducing the residual stresses at the manufacturing stage;
• control of the welding procedure to prevent water entrapment at weld joints.

3.3 Gauge corner defects

These effects are formed on the high rails in curves of sharper radius generally andon routes of heavy axle loads with moderate speeds.

First, the shear stress appears at the elliptical shell-like crack with characteristic crack growth rings propagating transverse to rail section under the influence of contact stresses.

Later, due to bulk stresses and residual stresses in the rails, cracks initiate from the shell either upward or downward. The upward cracks lead to shelling on the gauge face, where as downward propagation will lead to fracture/formation of cracks.

A preventive practice could be the use ofhead hardened rails manufactured by clean steel making process and suitable steps for shifting and spreading the contact area away from the gauge face by conformal grinding.

4 Wheel rail contact

When two bodies (wheel and rail) are in contact, stresses and strainsappear. A large force from the first body (wheel) is transferred to the second body (rail) through a small contact region about 1 cm^2.

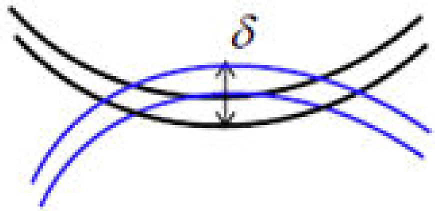

Fig. 2 - Wheel rail contact

Fig. 3 - Material yielding and fatigue

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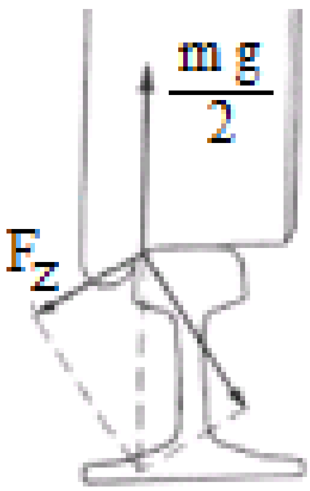

Fig. 4 - Rolling contact forces

Fig. 5 - Rolling contact forces combined with friction induce wear

Wheel rail contact regions, figure 6:

a) Region A - wheel tread rail head contact:
- most common contact region;
- lower contact stress.

b) Region B – wheel flange rail gauge corner:
- much smaller contact area and more severe;
- higher contact stresses and wear rates.

c) Region C - wheel and rail field sides contact:
- least likely contact region;
- high contact stress.
- undesirable wear lead to incorrect steering of wheelset.

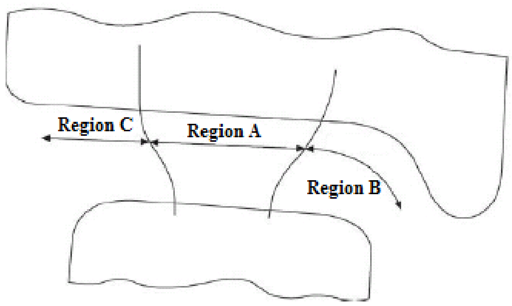

Fig. 6 - Wheel rail contact zones

5 Creep

When a wheel deviates from pure rolling (during traction, braking or curving) “creepage” in the contact patch occurs due to the different velocity of material in the wheel and the rail.

Creep is defined as a small apparent slip due to the difference between the tangential strains in the two bodies, figure 7.

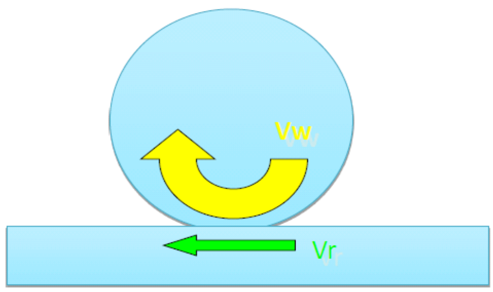

Fig. 7 - Creep in the wheel rail contact zones

The existence of friction forces at the interface between the rolling elastic bodies results in the division of the contact area into a region of micro-slip and a region of adhesion where the surfaces roll without relative motion stick-slip zones.

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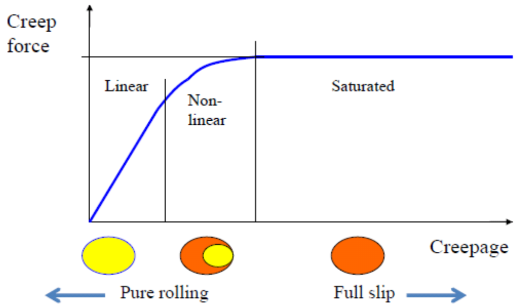

Fig. 8 –Types of creep force

For small creepages the creepage-creep force relationship is linear and the linear "creep coefficients" can be calculated. At high creepages (full slip) the creep force is limited by the product of the normal force and the coefficient of friction. Between these, the relation of the slip is quite nonlinear. Creep forces must be calculated in lateral, longitudinal and spin directions but these are not independent as saturation (μN) occurs. These forces play an important role in the guidance and stable running of the railway vehicles.

6 Conclusions

Rolling contact fatigue damage in railway wheels operating under high axle loads includes surface initiated cracking and sub-surface shelling. Surface-initiated cracking and shallow (3-5 mm depth) shelling behavior has been reduced through increases in material strength and improved management of the wheel-rail interface (in order to control contact stress and creep age levels).

Wheel inspection procedures and analytical approaches to rolling contact fatigue behavior in wheels are reviewed on an ongoing basis, in conjunction with routine tracking of wheel performance, in order to minimize the probability of rim shelling failures at current and future axle loads.

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