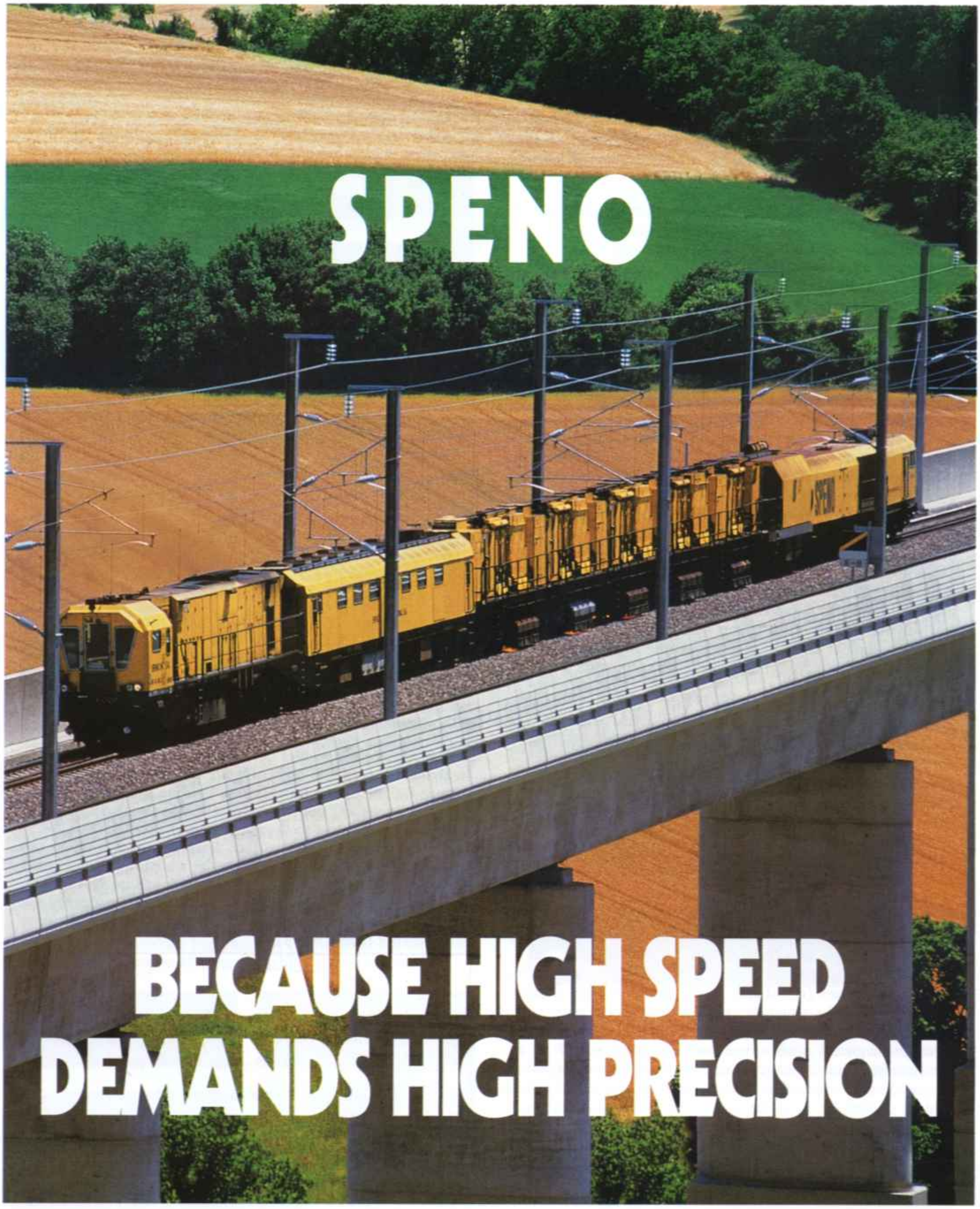
RAIL ENGINEERING INTERNATIONAL



Grinding of rails on high-speed railway lines: a matter of great importance

Today, a great number of high-speed railway lines are in revenue service around the world. Some dedicated high-speed railway lines in Europe allow speeds of up to 330 km/h. In Germany, some lines are shared between high-speed passenger train operation during daytime and freight train operation during the night. There is no doubt that, at high train speeds, high dynamic forces are generated. Contact forces from the powerful acceleration of motorised axles amplify surface stresses in the wheel/rail contact zone. Guiding the wheelsets safely and smoothly in curves and keeping them stable in tangent track requires tight tolerances for the contact geometry of the rail head. Thus, maintaining appropriate rail head conditions by means of grinding is a matter of great importance for high-speed railway lines.

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RAIL SURFACE DEFECTS ON HIGH-SPEED RAILWAY LINES

Rail grinding embraces the treatment of rail surface defects concerning:
— the longitudinal profile;
— the transverse profile;
— the wheel/rail contact zone;
or a combination of these three parameters.

Longitudinal profile

At high train speeds, the dynamic forces resulting from any small irregularity in the longitudinal plane of the rail head multiply the static load considerably – a perfectly even rail surface is, therefore, a must.

The specific layout of high-speed railway lines means that there are no curves with small radii that might provoke short waves on the low rail. However, short-pitch corrugation can occur in tangent track, particularly in the presence of high track stiffness (Fig. 1). Consequently, heavy concrete sleepers on intensely compacted ballast increase the possibility of corrugation occurrence.

Short-pitch corrugation causes an increase in noise during the passage of trains. At high train speeds, even irregularities of around 0.03 mm in depth can create discomfort for passengers and wayside residents. In Japan, rail grinding is mainly conducted to combat noise. Twice a year, the high-speed railway lines in this country are ground, in order to provide a smooth ride for the "bullet" trains.

Short-pitch corrugation does not only cause an increase in noise, but also vibration of the track structure in general, with a risk of overstressing track components.

Transverse profile

The interaction between wheel and rail is of importance for two reasons:
— the transfer of large forces within a small zone;
— wheel guiding stability.

If the geometry of the rail head does not optimally match that of the wheel tread, the contact stresses may exceed material fatigue limits. Sooner or later, this will result in surface cracks on the rail head, usually referred to as "headchecks".

Even with new track, rail surface conditions are not always perfect. Tolerances (rail shape, fastenings, etc.) may cumulate towards a negative situation. Modern rail types, particularly head-hardened ones, have a very low wear rate, almost close to zero. Consequently, their shape does not adapt quickly to the ideal profile. Thus, initial grinding of such rails after installation is now common practice, in order to provide optimal wheel/rail contact conditions from the very beginning. Simultaneously, imperfections in the longitudinal profile, such as damage from construction activities, ballast stone imprints or irregularities around welds, can be corrected.

Fig. 1: Short-pitch corrugation in an early stage (above) and in an advanced stage (right)

Fig. 2: Headchecks at gauge corner, widely spaced (left) and densely spaced with single ballast stone imprint (right)

Anti-headcheck rail profiles

In shallow curves, the high rails are particularly prone to rail surface fatigue in the form of fine hairline surface cracks, so-called headchecks, due to consistent wheel/rail contact in a fairly small zone close to the gauge corner (Fig. 2).

In order to delay rail surface fatigue, an appropriate rail head profile is required that shifts the wheel/rail contact zone laterally (later natural wear, though small, will bring it back to the sensitive zone again). These so-called anti-headcheck rail profiles have proven to be beneficial in that these provide some gauge-corner relief (Fig. 3).

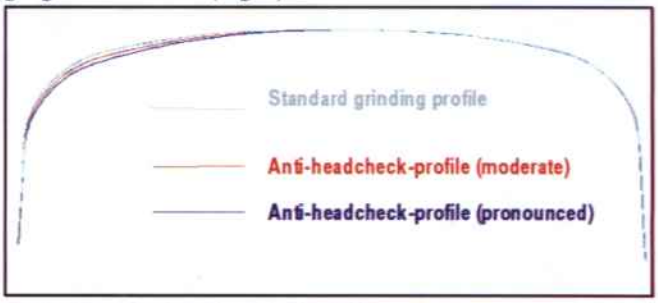

Fig. 3: Principle of anti-headcheck profiles

Another approach is to allow only negative tolerances with respect to the standard target profile, in order to avoid forced wheel/rail contact in a concentrated zone near the gauge corner.

High-speed rail profiles
At increased speeds, trains react more sensitively to any lateral irregularity, the controlling parameter being the "equivalent conicity". The influences from the track on this parameter are the rail profiles, the rail inclination and the width of the rail gauge. The higher the train speed the lower the equivalent conicity must be, in order to ensure smooth lateral movement. For line speeds of above 200 km/h, the appropriate value is around 0.1, and should not exceed 0.3. A conicity value of below 0.05 is also not acceptable, as it weakens the self-centring capability of the wheelsets, which may lead to flange contact in tangent track.

To ensure smooth self-centring of the wheelsets in tangent track, the rail gauge should be kept relatively wide. In this way, lateral oscillations are smoothed out and unstable running conditions, often referred to as hunting, do not occur. Where the width of the rail gauge is insufficient, it can be corrected by grinding gauge-widening profiles.

Lateral running stability can also be improved by applying high-convexity rail profiles that ensure a lower equivalent conicity. In this respect, Austrian Federal Railways (ÖBB) have developed a particular target profile for tangent track and shallow curves of high-speed railway lines (Fig. 4). By using a 130 mm crown radius, a 60 mm shoulder radius and a 22 mm gauge radius, this profile provides ideal running conditions.

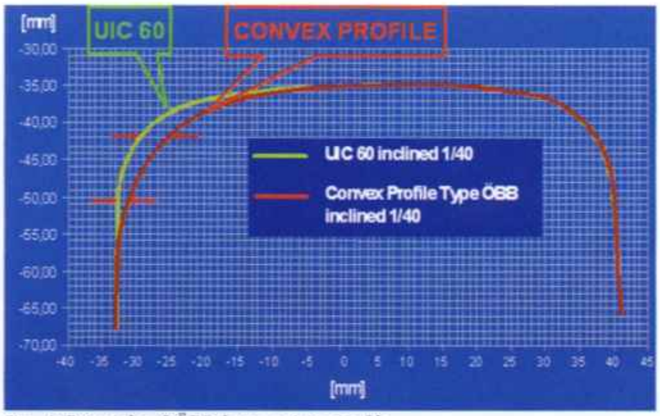

Fig. 4: Principle of ÖBB low-conicity profile

Wheel/rail contact zone
Apart from geometric irregularities, the rail head can also suffer from a deterioration in surface condition. During the service life of the rail, rail surface damage and fatigue develop, which require treatment.

Rail surface damage
Some high-speed railway lines suffer from imprints on the rail surface. Trains passing at very high speeds cause air turbulence around and underneath the carriages. Ballast stones are sucked up. If these fall on the rail surface in front of a passing wheel they are crushed into the rail surface, leaving ballast stone imprints of varying depths (Fig. 5). Particularly sensitive to this phenomenon are areas around underpasses and cuttings. In wintertime, rail surface imprints may be due to accumulated ice falling from carriages when approaching warmer areas.


Fig. 5: Ballast stone imprints, small (left) and medium (right)

The rail surface imprints act like short-pitch corrugation, causing high levels of vibration and dynamic force. Usually, the rail surface imprints are up to 0.3 mm deep, though some are as deep as 0.5 mm. In order to avoid negative consequences, rail surface imprints are removed by annual grinding campaigns; usual metal removal requirement being 0.3 mm. In this way, a majority of the imprints is eliminated and the larger ones remaining are reduced to an acceptable depth until they are eliminated during the next grinding campaign.

Rail surface fatigue
Rail surface fatigue may manifest itself in the form of:
— *headchecks:* as noted earlier, when subjected to high dynamic forces or when the wheel/rail contact zone of the rail head is comparatively small, the rail steel may exceed its fatigue limit. In these conditions, rail surface fatigue occurs in the form of headchecks, in particular on the high rails in curves. If left untreated, the cracks continue to grow – sometimes upwards, resulting in flaking and spalling, and sometimes downwards, leading to a possible rail breakage.

  Timely removal by means of rail grinding can keep the development of headchecks under control. It is essential to intervene at the right moment, as the crack growth rate increases with time and the dispersion of crack depths can vary considerably later on. Grinding cycles aimed at a metal removal rate of up to about 0.5 mm seem to be the most beneficial ones, as these balance fatigue treatment and wear development. As outlined earlier, an appropriate anti-headcheck rail profile will help to reduce fatigue initiation and subsequent wear development;
— *squats or black spots:* in tangent track, the wheel/rail contact zone is situated more or less in the centre of the rail head. Sometimes isolated surface cracks appear that extend below and parallel to the rail surface, and develop into so-called squats or black spots. These cracks may, occasionally, proceed downwards and, finally, result in a complete rail breakage. When rails are ground in fixed cycles, such defects are removed in an early stage and, therefore, in principle, do not give rise to catastrophic failures;
— *Belgrospi's:* on rails affected by short-pitch corrugation, another rail surface fatigue phenomenon has been observed. On the crests, a network of cracks appears, a sort of mixture of irregular headchecks and small squats, with the risk of subsequent severe damage. First detected on a high-speed railway line in Germany by three engineers, named Belz, Grohmann and Spiegel, these are known as "Belgrospi's" (Fig. 6). It has been found that 0.03 mm deep short-pitch corrugation can increase the dynamic forces sufficiently to result in this kind of rail surface fatigue phenomenon.

Fig. 6: Example of Belgrospi's

APPLICATION OF RAIL GRINDING
The rail defects described occur sometimes isolated, sometimes in combination. In all cases, a timely intervention by means of rail grinding is preferable.

Rail grinding strategies
Various rail grinding strategies are adopted, depending on the prevailing track characteristics of the high-speed railway line.

Rail grinding based on inspection results
If applicable, corrugation recordings can be used to programme rail grinding work. For conventional railway lines, often an intervention threshold depth of 0.05 mm is specified. High-speed railway lines, however, are more sensitive to longitudinal irregularities. Therefore, in Germany, for instance, the intervention threshold for high-speed railway lines has been set at a depth of 0.03 mm. Some railways, particularly in Japan, use noise level recordings for grinding programming purposes.

Cyclical grinding
Up to now, rail surface fatigue defects could not be recorded in an useful manner for programming grinding. In practice, this lack of information about defect severity has been overcome by cyclical grinding interventions. Based on defect growth rate, usually known from experience gained in practice, appropriate grinding cycles have been determined satisfactorily. In places where an appropriate cyclical grinding strategy was not adopted, heavy repair grinding or even complete rail withdrawal and replacement was necessary.

Operational aspects
Operationally, regular maintenance activities, planned well in advance, help to reduce track possession requirements.

On high-speed railway lines, stabling points for track maintenance machines tend to be located far apart, and work is possible only during the night. To maintain rails efficiently in such conditions, some railways use heavy-duty rail grinding machines that can do the work in one pass. For metal removal rates of more than 0.3 mm, rail grinding machines can be coupled together to execute long passes at a fairly high working speed. In this way, some 25 km of track can be treated in one shift.

Rail grinding in turnouts
Track work is particularly sensitive to rail surface damage. Running from stock rails to switch blades and over frogs, usually mobile ones, always implies higher dynamic forces and lateral movements. Squats on swing-nose frogs and headchecks on turnout rails have frequently been observed on high-speed railway lines.

Several railways have started to grind rails in high-speed turnouts in the same way as rails in plain track. To maintain the ideal profile of the rail head also throughout the turnout is of particular importance. As-inclined rail head profiles on vertically mounted rails are standard today. Even anti-headcheck rail profiles in switches have been tested successfully.

On the longer high-speed turnouts, larger switch grinding machines can be used to advantage. When grinding turnouts, particular attention needs to be paid to dust control and cleaning of the ground area, in order to avoid malfunctioning of the switch.

CONCLUSIONS
Rail grinding is an integral part of track maintenance on high-speed railway lines. Today, all newly constructed high-speed railway lines are ground before commercial service commences. Grinding programmes are frequently executed to keep noise and vibration at acceptable levels and, thus, enhance passenger comfort. In some places, rail grinding is conducted regularly, in order to remove rail surface damage. Virtually all high-speed railway lines suffer from rail surface fatigue and require cyclical grinding. Special anti-headcheck rail profiles, as well as high-convexity rail profiles, have been introduced successfully on high-speed railway lines. In short, grinding of rails on high-speed railway lines is a matter of great importance.

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