Target profile selection & production tolerance specification for rail grinding: considerations towards defining guidelines

Rail grinding has become an indispensable aspect of track maintenance. In Europe, rail grinding acceptance criteria have been established with all rail infrastructure managers, which have become part of various European CEN norms. However, there are currently no specific guidelines as to what target profiles are to be selected and what production tolerances are to be specified that could be applied generally. In this article, considerations are put forward that have resulted from discussions within the European Rail Maintenance (ERM) Group (an informal think-tank that was formed following the completion of the Innotrack project), which may contribute towards defining guidelines for target profile selection and production tolerance specification for this type of track maintenance work.

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Rails are manufactured with a rail head geometry that generally suits ail possible wheel/rail contact conditions [1]. As a result of train operations, however, rail surface defects and irregularities occur, which can be removed by means of rail reprofiling (grinding, milling, planing, etc.) whereby, depending on local track conditions, often the removal of only a small amount of metal is required. Thus, throughout their entire service life, rails need to be reprofiled at certain intervals, in order to maintain optimum wheel/rail contact conditions.

The following rail reprofiling applications can be distinguished:

- initial reprofiling of new rails (removal of the decarburised layer formed during production and of any surface damage formed during installation, and optimisation of the rail head profile);
- corrective reprofiling (removal of, more or less, severe rail head surface irregularities, such as corrugation, surface damage, rolling contact fatigue (RCF));
- preventive or cyclic reprofiling (removal of small defects and maintaining good wheel/rail contact properties).

For discussing rail reprofiling, the following terms are key:

- nominal profile: the rail head profile as is specified in the European standard EN 13674-1:2011[1];
- target profile: the transverse rail head profile that is to be produced by rail reprofiling;
- special profile: the transverse rail head profile – different from the nominal one – that is produced for specific purposes.

When grinding rails, it is important to re-establish the design profile of the rail head or to produce an appropriate special one. The target profile needs to be selected and – depending on the adopted rail reprofiling technology – production tolerances have to be specified before the required work is ordered.

DEVELOPMENT OF TARGET PROFILES AND PRODUCTION TOLERANCES IN GERMANY AND THAT OF EUROPEAN CEN NORMS

For a better understanding of the current status regarding the selection of target profiles and the specification of production tolerances for rail grinding, it may be helpful to look at the development of these in Germany and that of European CEN norms.

Target profiles and production tolerances in Germany

In Germany, the discussion concerning target profile selection started in the early 1980s. At that time, rail reprofiling mainly concerned the longitudinal rail head profile, i.e. the elimination of corrugation, whereby the adopted technology of rotating grinding stones also improved the transverse rail profile. However, the fixed arrangement of the grinding angles only allowed a limited shaping of the rail head. This changed, in the 1980s, with the introduction of pivotable grinding units. However, as these featured very rudimentary grinding stone patterns, they occasionally had an undesired side effect in that the multiple passes using them, at times, led to previously unknown wheel/rail contact properties: an undefined shape of the rail head with two contact bands in tangent track.

The 1980s also saw the introduction of high-precision instruments in Germany that allowed the transverse rail profile to be measured, and thus – for the first time – the rail head geometry could be checked in a detailed manner, which initiated investigations into transverse rail profile rectification. As a result, new grinding stone patterns were developed, aimed at producing a "good" rail head profile which, at the time, was described as a profile close to the design profile of the installed rail following initial grinding.

At the time, aiming at technical excellence and payment per shift allowed the rail grinding operator in charge to approach the nominal profile of the installed rail following initial grinding as closely as considered necessary. Following each grinding pass, the transverse profile (bath rails) was measured at only one point within each grinding section, considering the results to be representative for the entire grinding section, until the target profile was achieved as closely as possible. This, of course, left much room for interpretation. Usually, the subjective decision of when this was the case was made by the grinding supervisor who, in those days, always used to be present on site.

With the appearance of competition and the introduction of terms like "aggressive grinding" and "high-production grinding", as well as the need to control grinding costs, acceptance criteria for rail reprofiling needed to be established. First of all, alternatives to describe the finished condition had to be defined (at the time, the target was still the nominal profile of the installed rail following initial grinding) and, as a result, the concept of production tolerances was introduced.

In order to define values for production tolerance limits, extensive recordings of ground rails were made, which yielded that the majority of the finished profiles were within a range of +/-0.3 mm of the target profile. By chance, this coincided with recommendations from high-speed wheel/rail interface experts. Consequently, this tolerance range was proposed as a standard requirement for ail rail grinding work in Germany. However, it soon became clear that the available duration of track possessions did not always allow the required number of grinding passes to be performed to achieve this. For instance, this was often the case when correcting short-wave corrugation on low rails in curves. As a high precision was not necessarily required here, a second production tolerance range (+/-0.5 mm) was introduced.

Further, tests conducted using modern rail grinding machines revealed that by producing a more convex profile (undercutting gauge and field sides) of the low rail in curves significantly delayed the re-occurrence of short-wave corrugation. At these locations, undercutting the nominal profile on bath sides of the contact band by up to 1 mm was considered ideal. Thus, a third production tolerance range (+0.7/-1.0 mm) was introduced for such specific cases. This category also allowed an increase in productivity on secondary railway lines requiring less demanding tolerances. Furthermore, it was still the grinding supervisor from the railway company present on site who decided on the number of grinding passes to be performed and when the work was considered to be completed.

In February 1996, the first set of criteria ("guidelines") for the execution of rail reprofiling was finalised in Germany which, following their application and experience gained in practice, and influenced by the European CEN specification project – see next section, saw a revision that led to the publication of new guidelines in 2003.

Development of European CEN norms

In April 1995, a working group, embracing representatives from DB AG, SNCF, SNCB, British Rail, Scheuchzer and Speno International, was set up that was assigned with the task to draft European specifications for rail reprofiling, for which the German guidelines finalised in February 1996 served as a basis. It immediately became clear that national requirements (and even pride) would make the drafting process very challenging.

The three production tolerance ranges adopted in Germany (+/-0.3 mm, +/-0.5 mm, +0.7/-1.0 mm) were heavily discussed, but they have finally been incorporated in the European specifications for rail reprofiling. Further, there was a consensus that the target profile should always be aimed for as closely as possible, and that any inevitable deviations from the target profile should be symmetrically distributed. Also, the widest tolerance range (+0.7/-1.0 mm) should only be selected in specific cases.

In 1998, the concept to allow a certain percentage of the ground length to be outside the specified tolerance limits was introduced, in order to accept larger deviations from the target profile in certain locations.

For many technical and political reasons, it took until 2002 before the working group could present a complete draft "Acceptance of rail grinding, milling and planing works in track", which was finally published in 2006, when the request came to immediately start a revision that eventually resulted in the European standard EN 13231-3:2012 [2].

CONSIDERATIONS TOWARDS DEFINING GUIDELINES FOR TARGET PROFILE SELECTION

As noted earlier, rail grinding was originally aimed at re-establishing, as much as possible, the design profile of the rail head. However, this does not always provide the best wheel/rail contact conditions and, therefore, a variety of alternative target profiles should be considered. For instance, specific profile adaptations for rails in tangent track, as well as for low and high rails in curves can be selected. In a similar manner, target profiles for different train operating conditions (e.g. high-speed, heavy-haul and mixed-traffic) can be considered. In this context, it is important to note that wheel profiles vary according to the type of rolling stock in use and their wear conditions.

Thus, in general, when selecting target profiles, the shape of the wheel profiles predominantly in use on the respective railway line and the respective track conditions (curvature, track gauge, rail steel grade, prevailing defects, etc.) should be taken into consideration.

Target profile selection - recommendations

From the aforementioned, it follows that it is necessary to select the target profile that is most suited for the prevailing local track conditions.

Standard (default) condition – nominal profile

If the prevailing local track conditions do not require any specific measures (or are not clear), then the best option to follow would be to select the nominal rail head profile that is mostly adopted on the high-quality track of the respective railway network, e.g. 60El at 1 in 20 inclination, or 60E2 at 1 in 40.

Specific conditions

Depending on the specific prevailing local track conditions, such as the presence of RCF (in particular headchecks), excessive lateral wear (usually in curves featuring small radii), tight track gauge, etc., the grinding of special profiles should be considered.

Tangent track

To ensure a smooth self-centring of the wheelsets on tangent track, the track 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. In case of a tight track gauge and running instability (hunting), in particular in combination with high train operating speeds, the grinding of "gauge-widening" or "conicity-lowering" profiles should be considered. In Fig. 1, an example of a gauge-widening profile is shown.

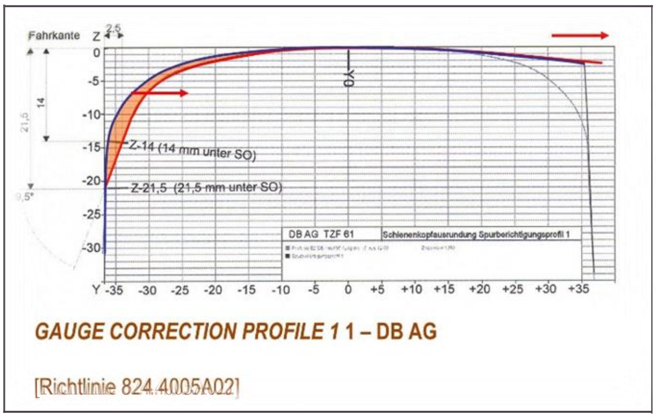

Fig. 1: Gauge widening profile DB AG

At increased operating 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 profile, the rail inclination and the track gauge. The higher the train operating speed is, the lower the equivalent conicity must be, in order to ensure a smooth lateral train movement.

If gauge-corner fatigue is present on tangent track, very often in combination with a tight track gauge, the grinding of "anti-headcheck (AHC)" profiles, such as the 54E5 profile according to the European standard EN 13674-1:2011 [1], shown in Fig. 2, could be a viable option.

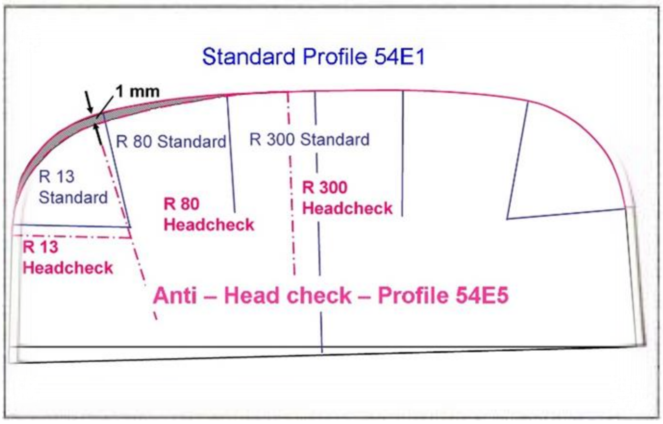

Fig. 2: Anti-headcheck profile 54E5 according to EN 13674-1:2011 [1]

Curved track
Rail wear behaviour in curves varies, in that:
- in shallow curves (radii larger than 500 m), the high rails often suffer from gauge-corner fatigue. In this case, the grinding of "anti-headcheck (AHC)" profiles should be selected. In Fig. 3, a selection of various AHC profiles that have been tested in practice are shown [3];

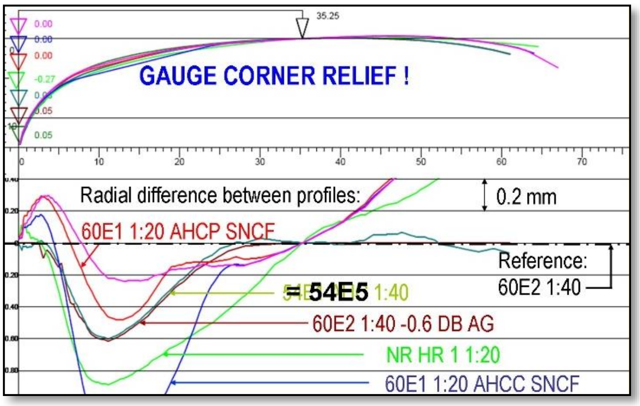

Fig. 3: Examples of testai anti-headcheck profiles – INNOTRACK [3]
AHCP: anti-headcheck preventive
AHCC: anti-headcheck conective

- in sharp curves (radii smaller than 500 m), the high rails are usually characterised by a high occurrence of lateral wear. In such situations, the grinding of "wear-reducing" profiles (often referred to as "asymmetric") would be the preferable choice (Fig. 4).

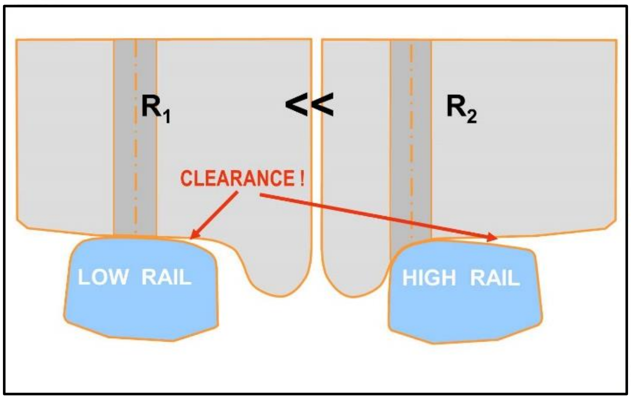

Fig 4: Wear reducing – asymmetric - profiles

In both of the above cases, the low rails can be ground until the nominal profile is achieved, whereby the adoption of negative production tolerances (below the target profile on both sides of the contact band) is recommended.

Switches and crossings
Ideally, on a given route, the wheel/rail contact conditions should be constant both on plain track and in switches and crossings. Therefore, it is recommended that the same target profile is selected for the reprofiling of rails in switches and crossings as is adopted for the rails of the adjoining plain track.

Further, in the past, rails in switches and crossings were often mounted vertically for construction reasons (Fig. 5), resulting in load concentrations towards the gauge corner of the rail head. When grinding, it does not make sense to re-establish the original (vertical) rail profile. On the contrary, initial reprofiling (if carried out) and any subsequent grinding action should aim at the as-inclined rail head geometry that is featured by the latest generation of switches and crossings, as this results in better wheel/rail contact properties (Fig. 6).

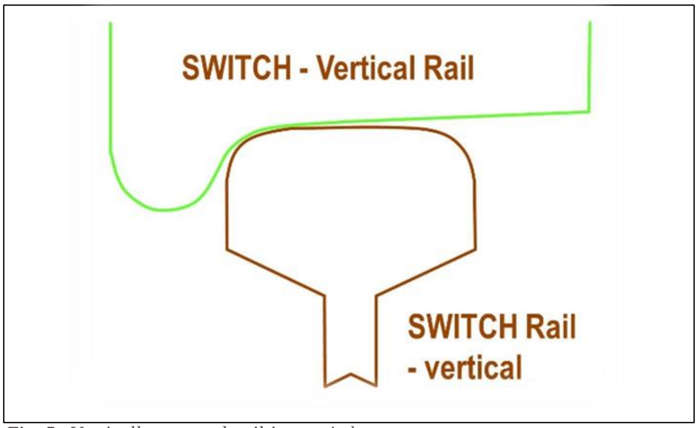

Fig 5: Vertically-mounted rail in a switch

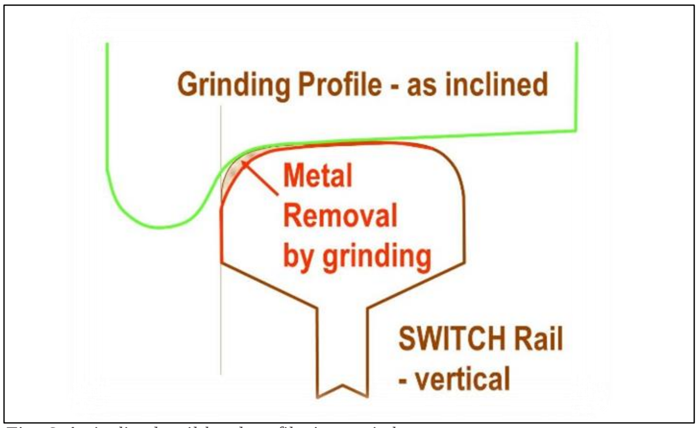

Fig. 6: As-inclined rail head profile in a switch

Transition between different target profiles
Between different target profiles, no particular transition requirements have to be specified, as usually the grinding process ensures that there is a smooth blending and that, thus, the wheel/rail contact conditions do not abruptly change in these zones.

Only if there is a large difference in metal removal rates (e.g. over 2 mm), a certain transition length (e.g. 10 m) needs to be considered.

CONSIDERATIONS TOWARDS DEFINING GUIDELINES FOR PRODUCTION TOLERANCES

The dimensions of any piece machined by tools are produced within, more or less, tight deviations from target values. Production tolerances may be defined that lie symmetrically or asymmetrically around the target. The same applies for rail reprofiling.

When reprofiling rails, the following dimensions need to be specified:
- the amount of metal to be removed, in order to achieve defect elimination or reduction;
- the shape of the transverse rail head profile;
- the evenness of the longitudinal rail head profile.

In the rail reprofiling context, the target profile is usually described as a set of x-y coordinates and concerns the area of the rail head where wheel/rail contact is expected (usually ranging from the -70° tangent at the gauge side of the rail head (this corresponds to the maximum wheel flange angle) to the +5° tangent at the field side.

The target profile can only be created by taking away metal (no metal can be added). This means that the target profile is approached from a larger value (positive tolerance limit) and then gradually reduced to achieve the target value, as is illustrated in Fig. 7, thereby remaining within both the positive (above the target profile) and the negative (below the target profile) production tolerance limits, which may either be wide or tight, as is illustrated in Fig. 8.

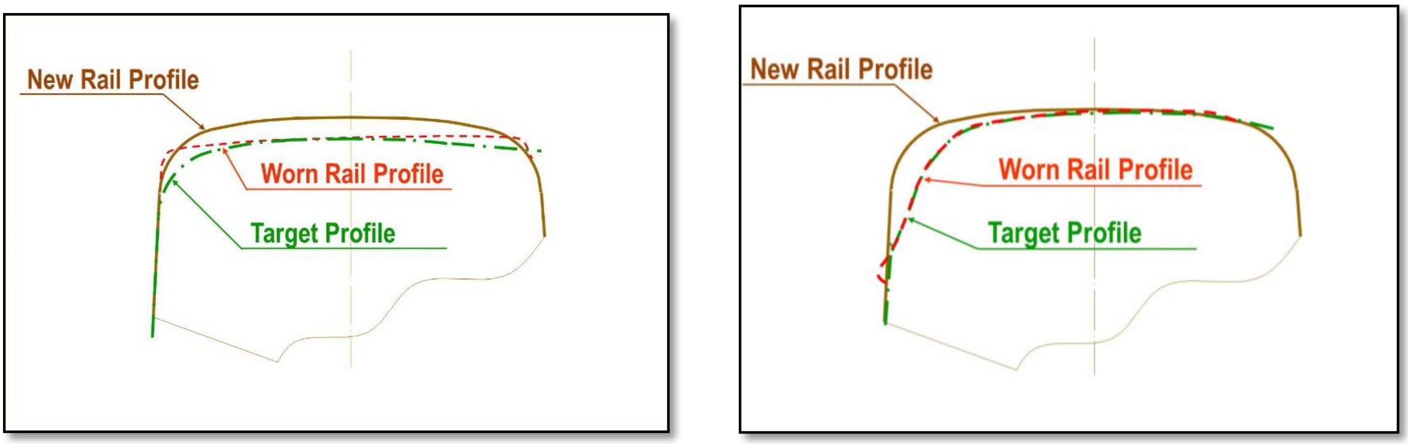

Fig. 7: Examples of creating the target profile based on a worn rail head profile

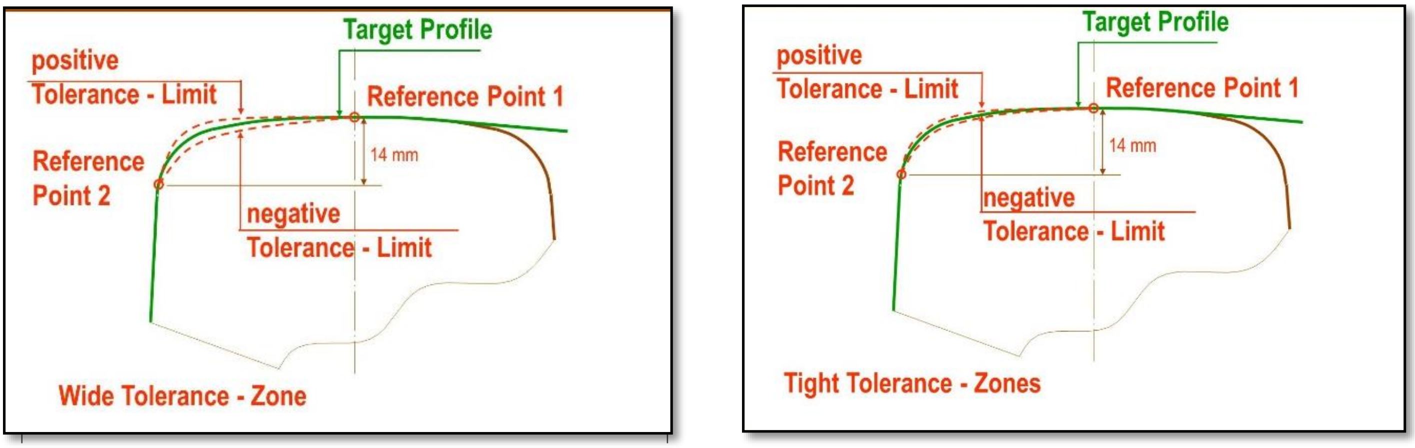

Fig. 8: Examples of tolerance zones (on the left: wide, on the 1ight: tight)

In order to get as close as possible to the target profile, a number of grinding passes with small metal removal rates (the closer to the target the smaller) may be required, thereby avoiding the removal of too much metal per pass.

The wider the production tolerance bands are, the easier it is to reach grinding work acceptance and the higher the production rate is.

The use of technologically-sophisticated work systems and experience gained in practice usually allow the rail reprofiling process to be controlled in a way that the target profile is reached sufficiently close within a minimum of time. The grinding machine operator may be tempted to produce a profile that lies just below the upper tolerance limit, whereas the client usually would like the ideal profile, i.e. one with the smallest possible deviations, to be produced, in order to ensure optimal wheel/rail contact conditions.

Further, positive production tolerances (above the target profile) may increase the risk of load concentration at the gauge corner of the rail head; whereas negative tolerances (below the target profile) may increase the risk of load concentration at the centre of the rail head.

Thus, the specification of production tolerances is faced with the dilemma of achieving either:

– a high finished quality (with a durable effect) by adopting tight production tolerances, resulting in a lower production output and, thus, higher unit costs; or
– a lower finished quality by adopting wide production tolerances, resulting in a higher production output and, thus, lower unit costs – however, with the risk of a short-duration benefit.

Consequently, the specification of production tolerances for rail reprofiling is a delicate task that should always take into account the purpose of the reprofiling intervention (e.g. corrugation removal, asymmetric profiling, RCF control).

Production tolerance specification as **per European standard EN 13231-3:2012**

A good way to check the efficiency of selected target profiles and adopted production tolerances is to observe the location and width of the wheel/rail contact band following reprofiling – small enough to ensure well-defined running conditions in the right place, and wide enough to limit the risk of RCF.

As noted earlier, in European standard EN 13231-3:2012 [2], the following three production tolerance classes are given:

- *Class Q (+/-0.3 mm)*, which is recommended for adoption on main lines, i.e. with high-density heavy-haul (20:25 t axle load) traffic or traffic operating at speeds of V 20: 160 km/h. It ensures good wheel/rail contact conditions and can be produced economically by means of any rail reprofiling process;
- *Class R (+/-0.5 mm)*, which is recommended for adoption on ail other lines, usually with less demanding conditions (e.g. low line speed, low axle load, low train frequency), where a wider production tolerance band would be acceptable;
- *Class S (+O.7/-1.0 mm)*, which is recommended to be adopted only as an exception (e.g. on secondary lines). It provides the possibility to reduce the amount of metal to be removed by means of reprofiling (higher production rate for grinding, leaving a flatter profile) or to change the profile voluntarily (heavy gauge-corner relief). However, in such a case, it is recommended to specify a special profile using a tight tolerance, in order to achieve consistent wheel/rail contact conditions.

Some flexibility with regard to asymmetry around the target profile is provided in that, in specific cases, asymmetric tolerances (e.g. 0/-1.0 mm or +0.2/-0.4 mm) could be envisaged, e.g. for gauge-corner relief. However, the better option would be to specify a special profile with tight asymmetric tolerances, as only this would ensure a result that is consistently close to the target profile.

Sometimes there are short sections of track that cannot be reprofiled within the specified production tolerance limits, either because they have a very different profile from the majority of rails on a given railway line (e.g. plug rails), or because they pose a problem for the adopted rail reprofiling technology (e.g. level crossings, clearance problems near signalling equipment such as axle counters, etc.).

The European standard EN 13231-3:2012 allows some percentage of the ground length to be outside the specified tolerance limits (see table below) [2].

Range of deviation	0.6mm	1.0 mm	1.7 mm
Class Q (+/-0.3 mm)	90%	95%	98%
Class R (+/-0.5 mm)	Not applicable	85%	98%
Class S (+0.7/-1.0 mm)	Not applicable	Not applicable	75%

Percentage of ground length allowed to exceed specified tolerance limits according ta EN 13231-3:2012 [2]

Perhaps, in specific circumstances, e.g. in the case of cyclic grinding regimes, where Class Q might be too demanding for a high production output requirement and Class **R** would be seen as too generous, it might be worthwhile to consider an intermediate class with a respective percentage of ground length that may exceed production tolerance limits (e.g. 60% 0.6 mm, 80% 1.0 mm, 98% 1.7 mm – or other intermediate ranges).

FINAL REMARKS

Rail grinding has become an indispensable tool to extend the service life of the rail. If the right parameters for its execution are selected, the positive effects it has on the service life of the rail can be further expanded. This applies, in particular, to the selection of the appropriate target profile and the specification of respective production tolerances.

ACKNOWLEDGEMENT

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