Efficient implementation of modern rail maintenance technologies

Richard Stock, Michael Seeleithner

The flexible selection and application of the appropriate rail maintenance technology is the basic condition for a safe and sustainable railway system with optimised life of track and rails.

1 Historical background

From the earliest days of the railways in the 19th century, railway infrastructure managers (RIM) have been grappling with the effects of the high forces between wheel and rail which lead to damage of the main system component - the rail. When the first steam locomotives started to take over from horse-drawn railways, the rails installed frequently failed within a very short time due to the sharp rise in axle loads and traction forces. The materials development over the last 165 years or so (in Germany and Austria, the first railway lines for public passenger transport came into operation between 1830 and 1840) has obviously made a decisive contribution to today's rails having a service life in the track of several decades due to the use of state-of-the-art rail steels and to enduring accumulated loads of up to 2 million load tonnes. Nonetheless, modern steel rails, too, are grappling with the same problems as their "ancestors": plastic deformation of the microstructure, wear and formation of cracks (Fig. 1).

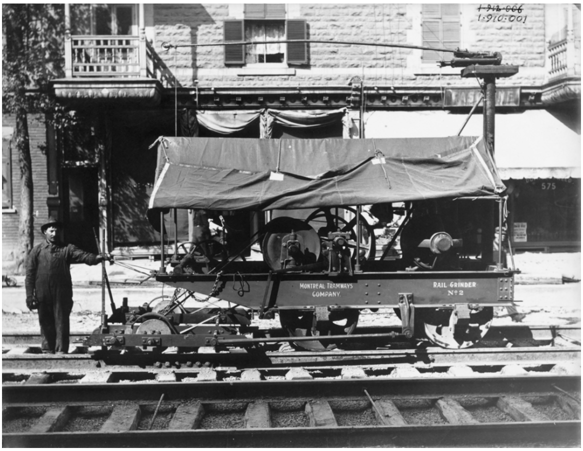

Fig. 1: Grinding machine for rail maintenance from the year 1912 in Montreal/Canada Source: wikimedia

2 Optimising the asset life

To achieve the long service life and accumulated load stability mentioned above, the infrastructure manager has a number of tools available which will be discussed in combination and with regard to their interaction. Isolated discussion of these components entails the risk of not achieving the success required and of even reducing the life of the asset. Only if optimisation takes place at the system level, can the asset life be extended considerably. These tools and components of the wheel/rail system are summarised in Fig. 2 and will be discussed in more detail below.

Selection of the suitable rail material depending on the profile of requirements and loads ensures the necessary basic life of the rails. On the one hand, modern rail materials have a high wear resistance and, on the other hand, delay the potential formation of cracks (rolling contact fatigue (RCF)) significantly. Research is currently looking at materials which are no longer susceptible to RCF; however, these material concepts are not (yet) available commercially.

Profile pairing between wheel and rail distributes the acting forces onto an optimised surface, thus reducing the stresses between wheel and rail and subsequently the damage arising. In Europe, one or two rail profiles are normally used by each railway company - one standard profile (e.g. 60E1) and one so-called anti-head check profile. An anti-head check (AHC) profile is based on a standard profile with the profile being undercut at the running edge by up to 1 mm which delays the formation of RCF at the running edge.

Dynamic forces due to singular or periodic track geometry defects lead to a local increase in the forces between wheel and rail which can result in a premature development of rail damage at these locations. A high-quality track geometry is a major contributor to reducing the dynamic forces between wheel and rail and thus has a positive effect on the service life of the rails.

Another option for affecting the rail service life favourably is rail conditioning, also referred to as friction management. This means that the coefficient of friction be-

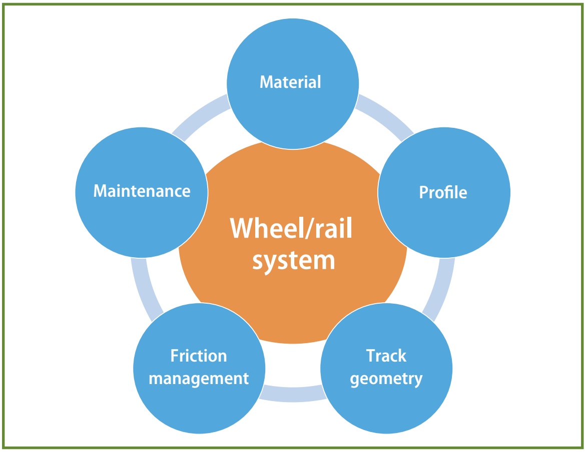

Fig. 2: Core components of the wheel/rail system

Source: Richard Stock

tween wheel and rail is manipulated or adjusted in a targeted manner. The most common form of rail conditioning is the rail side lubrication to reduce the side wear of the rails. For this, a lubricant (oil, grease, lubricant sticks etc.) is applied to the running edge of the rail via a fixed installation or to the flange face by a vehicle-based system to reduce the friction coefficient between wheel and rail in this area to a minimum. The second form, which is less common in Europe, is conditioning of the running surface of the rail with a friction modifier. This reduces high coefficients of friction between wheel and rail to a mean value in a targeted manner, not affecting the traction performance (braking, starting) of the vehicles [1]. Both measures have a positive effect on the service life of the rails as the tangential forces transmitted and the resulting shear stresses are reduced and thus wear and damage are delayed.

The final tool in the toolbox is rail maintenance. This removes existing damage and reinstates or adjusts the target profile of the rails as per specification. This article will address this aspect of this complex system in more detail.

3 The requirement for rail treatment

Rail treatment differs from the components (tools) of the wheel/rail system mentioned above as it does not just counteract the formation of rail damage, but also removes or corrects existing damage. The other components delay the formation of damage, but do not remove existing damage. This results in most cases in an obvious necessity for rail treatment, even if the other components of the system have already been fully optimised and adjusted.

3.1 Strategies for the extension of the service life of rails

A number of strategies are available to railway infrastructure managers to successfully use appropriate rail treatment technology to extend the service life of rails. This has already been discussed in detail in EIK 2020 [2]. This chapter briefly refreshes this important topic.
Extensive experience gained over the last 40 years shows that preventive maintenance is the most effective treatment strategy with regard to economic benefit as well as the service life of the rails. By regular grinding with a small removal of material, the rail surface is kept in a condition (almost) free from damage (Fig. 3, damage classification “starting”). Any damage arising between treatment intervals is removed again during the next planned treatment or reduced to a safe level.

The interval for preventive maintenance can be based on time or load. The optimum treatment intervals are determined on the basis of experience (observations, measurements) of the damage behaviour of the rails under the known load conditions. It is also important that

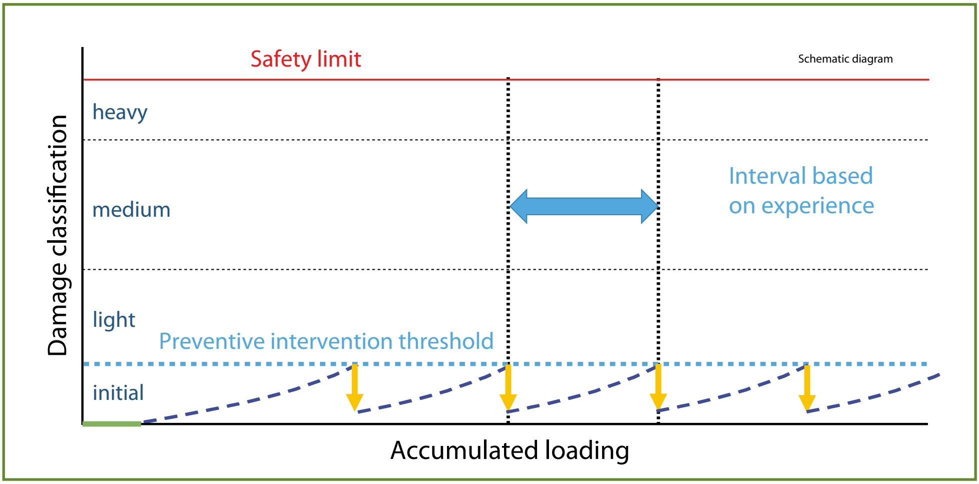

Fig. 3: Preventive maintenance strategy to maximise the rail service life Source: Richard Stock

the condition of the rails after treatment is recorded (measurement system) and that the load conditions over time are documented. A special form of preventive maintenance is the predictive maintenance. Due to its complexity and the "openness" of the system, the predictive strategy has so far been employed only rarely for rail maintenance. Nonetheless, the railway industry is focussing attention on this promising subject.

Even if a preventive maintenance strategy is the best approach, various internal as well as external circumstances can lead to damage of a magnitude which can no longer be dealt with by a preventive regime. And then a premature replacement of rails is imminent. A strategy is required for this case which enables the railway infrastructure manager to return efficiently and quickly to the preventive regime and thus avoid premature replacement of rails. The most efficient approach for this is a regenerative maintenance strategy (Fig. 4).

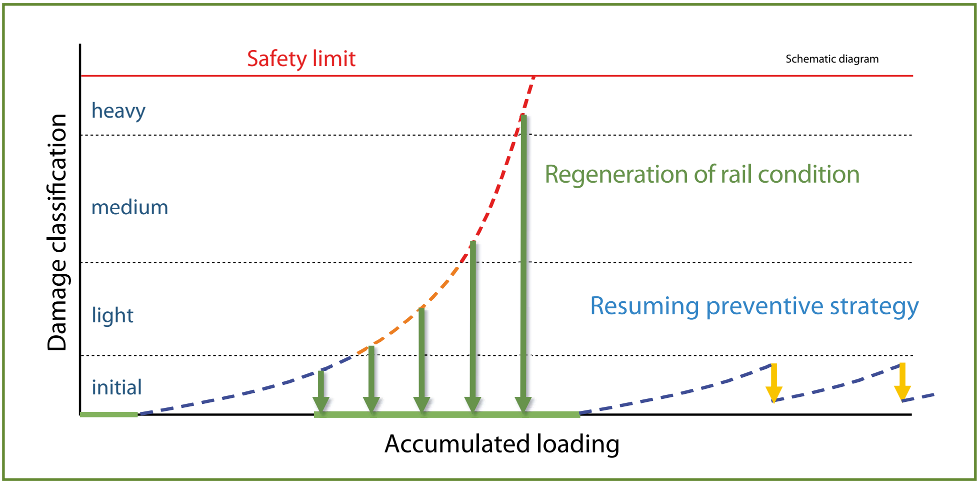

Fig. 4: Regenerative maintenance strategy as a condition for reinstating a preventive strategy

Source: Richard Stock

With a regenerative strategy, the damage to the rail is not simply corrected, but a rail condition free from defects is reinstated with precise longitudinal and cross profile almost independent of the starting condition of the rail (the rail is regenerated/renewed). Following this regenerative intervention, rail maintenance can continue with a preventive strategy.

4 Rail treatment technologies

To implement the required rail maintenance strategy, it is necessary to select the suitable maintenance technology. A number of technologies are available to the railway infrastructure manager for this purpose.

4.1 Conventional rail grinding

Conventional rail grinding uses cup wheels rotating around their vertical axis placed perpendicular to the rail face and which are pressed against the rail face at different angles with a specific pressure while the carrier vehicle moves along the rails. This creates a bevel along the rail due to the abrasive removal of material. By arranging several cup wheels one behind the other at appropriate angles and overlapping neighbouring bevels, the complete relevant area of the cross profile can be ground. The cross profile which can be adjusted flexibly then corresponds to a traverse. In addition to the typical bevels, conventional grinding creates a characteristic surface structure in the lateral direction to the longitudinal rail axis. This scoring arises due to the rotation of the cup wheels and the forward movement of the grinding machine. Typical grinding machines have at least 4 and a maximum of 120 cup wheels and can be designed as road/rail vehicle or rail-bound vehicle. To set the target profile required, the cup wheels in modern machines are aligned towards each other via computer control and partly in real time. Depending on the material removal required and the size of the machine, it may be necessary to pass over the section multiple times. Grinding with grinding machines is non-directional. Switch grinding machines are used for switches. These are adapted to the requirements of switches and crossings with a special grinding geometry and extended angle adjustment of the grinding units. Grinding technology is suitable for preventive maintenance due to the low quantity of material removed during each pass (depending on machine size up to 0.2 mm) and passing speeds of up to 20 km/h. Obviously, it is also possible to use this technology for corrective work. However, in this case the hourly capacity of completed track metres is considerably reduced due to the necessity of having to pass over a section multiple times. Due to the abrasive removal of material, dust (rail material, grinding wheel material) and sparking occur during grinding. Dust leads, on the one hand, to contamination of the machine and track environment and, on the other hand, can also present a health risk when work is carried out in tunnels. For safety reasons, switches in particular must be cleaned separately after rail grinding. Sparking results in a fire risk in tunnels, on bridges and in general in dry and thus easily flammable environments which must not be underestimated. For this reason, grinding trains are always equipped with water tanks and water cannons or sprinkler systems.

4.2 Peripheral grinding

For peripheral grinding, the grinding wheels rotate around the horizontal axis. The grinding wheel is normally set at a small angle against the longitudinal direction of the rails (offset angle). The grinding wheels can be driven or can rotate freely. The driven version is mainly used for the finishing step of rail milling (see relevant chapter further below). The non-driven version can be used only for preventive rail grinding at speeds up to 80 km/h. With this procedure, only the rail head is ground; the running edge is not affected. It is not possible to reprofile the rails or to remove damage to the rails; the existing profile is simply maintained. Only very little material is removed with this grinding technology; it is significantly below

0.1 mm for each pass. This procedures does not generate bevels and results in a diagonal surface structure (cross grinding). Sparking during peripheral grinding is reduced compared to conventional grinding and, due to the very low material removal, only very little dust is generated.

4.3 Belt grinding

Belt grinding technology is used to a lesser degree. An "endless" grinding belt is pressed against the rail surface by two guide rollers and one pressure shoe. The applied pressure controls the amount of material removed. Here, too, only the running surface on the rail head can be ground, with very little material being removed. The procedure is used mainly for finishing after rail milling and results in a directed sparking (Fig. 5).

Fig. 5: Belt grinder for finishing after rail milling

Source: Schweerbau International

4.4 Grinding with rubbing stones

Rubbing stones are rectangular or prismatic grinding stones which are pressed perpendicularly onto the rail running surface. The stones are either supported rigidly or carry out a limited oscillatory movement in the longitudinal rail direction. This procedure, too, is used primarily for preventive maintenance as only the rail head can be maintained, with little removal of material. Corrective measures are not possible with this technology (Fig. 6).

It results in a very smooth surface structure which is aligned in the longitudinal rail direction. This special surface structure has acoustic benefits compared to the other grinding methods. The oscillating stone method is limited to speeds up to 2 km/h and is also used for finishing after rail milling. The variant with rigid support of the stones can be used at up to 30 km/h and requires water cooling. Both variants grind the rail surface without sparking and almost without dust.

Fig. 6: Rubbing stone technology to generate a rail surface optimised for noise

Source: Plasser & Theurer

4.5 Rail milling

Rail milling is a rotational cutting process around the circumference where the rail material is cut from the rail surface as swarf. The cutting process is carried out dry, and the process heat is absorbed by the tool (milling cutter) and the swarf (Fig. 7).

The rail itself only heats up by a small amount. Milling is a process completely free from dust and sparking. The swarf is collected by means of a highly efficient vacuum system and then stored in the machine to be returned for recycling. The target profile required for the rail is set with the highest precision in longitudinal and transverse direction by means of the shape of the milling cutter and its carbide plates. Consequently, a separate milling cutter is required for each target profile. The milling cutters are available with diameters between 400 mm and 1445 mm, depending on the application range of the milling machine. An individual milling unit permits material removal of between 0.1 mm and 0.3 mm and up to 3 mm in a single pass. By integrating several milling units per machine, the maximum material removal per pass can be scaled up accordingly. As milling is a directional process, work can only be carried out in one direction. To be able to carry out a second pass, the vehicle must first reverse. Process speeds of up to 3 km/h are achieved, depending on the material removal required and the milling technology used.

Fig. 7: Rail milling technology: precise reprofiling of the rail due to the shape of the milling cutter

Source: Schweerbau International

Rail milling creates a characteristic surface structure in the form of regular scales or "bowls" with a depth of a few µm. Due to the regularity of this structure, it is possible that unwelcome noise effects ("singing" of the rails) occur immediately after milling until this structure has been smoothed and/or worn by train traffic. However, this can take some time depending on axle loads and frequency of trains. To avoid this annoying noise effect from the start, in urban areas in particular, milling machines are equipped with appropriate finishing technology which smoothes or polishes this residual waviness. For this purpose, either driven peripheral grinding, belt grinding or oscillating grinding with stones is used. It is characteristic for all these technologies that no reprofiling is carried out, but that only the surface is smoothed. Some milling machines are equipped with highly efficient spark and dust extraction for this process step so that the majority of the by-products are removed.

As a large amount of material is removed, the milling technology is excellent for the regenerative treatment of badly damaged rails which would otherwise have to be replaced. Milling is also used for cyclical preventive maintenance, in particular in those areas where factors such as surface quality, fire hazard and freedom from dust are important. Rail milling machines can be designed as rail-bound vehicles or as road/rail vehicles and are also suitable for work on switches and crossings – so that an additional "switch milling machine" is not required.

4.6 Rail planing

With rail planing, the material is lifted from the rail by rigidly fixed cutting plates during the forward movement of the machine. This produces long, curled shavings which are collected magnetically, instead of the small swarf from milling. The rail profile is set by an appropriate arrangement of straight and radius cutting plates. Using a rail planing machine, it is possible to machine both sides of the rail up to an angle of 80°. This process results in a very smooth surface with high accuracy in the cross and longitudinal profile. The process is free from dust and sparking and requires water cooling. This technology achieves very high levels of material removal (including rectification of the track gauge), and several passes are required to machine the complete cross profile. Various track installations, such as check rails, axle counters, lubrication equipment etc., must be removed before machining. However, rail planing is a niche product which is hardly ever used nowadays.

4.7 Rotary planing

The rotary planing technology is a combination of milling and planing. It combines the benefits of both technologies and eliminates one limitation of milling - the fixed target profile. Using this technology, the rails are machined without sparking or dust developing. The swarf is of a similar size to that arising from milling and can be collected much more easily than is the case for pure planing. The cutting tools which can be positioned individually carry out a rotary movement and are, when coming into contact with the rail, guided uniformly parallel to the rail surface for the duration of the contact. This results in a smooth rail surface without the usual surface structure after milling, so that the finishing step requires less effort. In addition, the target profiles of both rails can be changed independently and continuously during work by taking out individual cutters. The cutting tools (or cutting plates) are arranged on plungers on a rotary planing unit with a diameter of 1445 mm. Using this technology, it is possible to machine a switch including crossing and switch rails due to the flexible profile adjustment during machining. As for milling, track switches and check rails can remain in position. Rotary planing permits material removal of between 0.2 and 2 mm in one pass with a working speed of 300 to 1500 m/h.

5 Spoilt for choice: the road to the optimum wheel/rail contact

There are a number of strategies in combination with various technologies available to the railway infrastructure manager. The following criteria are of prime importance for the selection of the correct combination in each case:

- Initial situation: What is the reason for rail treatment and what has been done previously (previous work)?
- Technical criteria: The condition of the rails and the technical data of the railway infrastructure manager (axle loads, train frequencies, type of traffic and train frequency, track type, rail type, degree of damage, switch maintenance, plain line maintenance, length of maintenance window, etc.). What technical effects does maintenance have (e.g. extension of rail life)?
- Availability of technology: Is the desired technology available and usable at the time required?
- Organisational criteria: Is the railway infrastructure manager capable of supporting the strategy/technology/combination required logistically and with regard to staff? Frequently, additional internal hurdles, objections and reservations have to be overcome, in particular when introducing new technology.
- Legislative criteria: Are there laws or regulations which exclude or favour the use of certain technologies?
- Economic criteria: Which costs arise to the railway infrastructure manager from the use of a certain strategy/technology/combination and which cost savings can be achieved? This results in a conflict between the fact that costs usually arise immediately and savings will only be achieved over at least the medium-term.
- Other external criteria: Environmental effects and time of year can have an effect, even if only briefly, on the usability of technology. As we have all painfully learned in 2020 and 2021, pandemics are amongst the unpredictable external effects.

Although this list is nowhere near complete, it should cover a large part of possible and/or necessary criteria. It is obviously the aim of the railway infrastructure manager to maintain optimum wheel/rail contact, to have a rail free from defects and with the highest possible quality of profile and thus to maximise the life of the rails.

6 Real-life application examples:

Sufficient reports have been provided in the past on rail grinding and the various applications for preventive or corrective strategies. Refer to the key literature [3,4,5]. This section concentrates on milling technology which has been used successfully for about 25 years. In relation to the typical life cycles of the railway system, milling technology can nonetheless still be regarded as a new technology.

6.1 Application in Japan

In Japan, systematic rail maintenance using grinding was implemented only relatively late during the 1980s. This can probably be attributed to the low axle loads in Japan (passenger traffic, max. 16 t axle load, on average 10 t axle load) and also to the early use (from the 1950s) of high-strength heat-treated rails. Japanese railway infrastructure managers have been, however, among the first non-European railways considering milling technology. Despite various technical and logistic problems with the first rail milling machine in Japan, the Japanese railway infrastructure managers clearly recognised the benefits of milling technology.

- Rail grinding creates a large amount of grinding dust which contaminates the track environment, but also the grinding machine itself. Therefore, extensive cleaning work is required after use. Due to the composition and size of these particles, grinding dust has meanwhile been categorised as harmful in Japan, and this type of cleaning work must be carried out wearing appropriate protective equipment.
- Moreover, sparking during grinding continues to cause fires in the environment near the track despite various containment measures.
- Rail grinding can lead to undesirable material changes on the rail surface due to the heat transferred into the rails. The resulting surface roughness after rail grinding (scoring) frequently leads to undesirable noise effects and resulting complaints from residents.
- In Japan, the rails are usually treated with six to twelve passes of a grinding machine. During the typically short maintenance windows of about one hour, often only a few of the required passes are possible. This means that sections with an only partially ground cross profile remain, which does not meet the specifications. With milling, the target profile is reinstated 100% after only one pass, and partial treatment of the cross profile, even for brief time windows, is thus completely avoided.

6.2 Tailored rail treatment system

Based on this starting situation, Robel, a manufacturer of track construction machines, and Schweerbau International (SBI) in cooperation with Japanese customers developed a vehicle concept for rail treatment which was tailored specifically to the local circumstances. SBI has been involved with the development of milling technology and the construction of highly efficient rail milling machines for more than 15 years and has been making use of decades of user experience in track construction. SBI milling technology is used throughout Europe in urban as well as main line railways.

Fig. 8: Robel rail milling train for Japan with milling, polishing and measuring units

Source: ROBEL

High speed milling technology (HSM) forms the core of the two-part Romill vehicle concept (Fig. 8) for the Japanese market. In contrast to conventional milling technology, a large diameter milling cutter with specially arranged indexable cutter inserts is used here. Due to the larger number of cutter inserts in combination with the optimised cutter arrangement, the tool life travel of individual cutters is increased significantly and a tool change during a (night) shift is no longer necessary. Furthermore, up to 8 cutting edges can be used per cutter insert before the complete insert has to be replaced.

The unique selling point of this novel milling technology is that it permits machining of the rail independently of the track geometry, which conventional milling technology has not been able to do so far. The milling cutter is divided into multiple segments (cassettes) over its outside circumference. Thus, to replace or index the cutter inserts, only the segment and not the whole milling cutter is replaced.

On top of this, the segment is replaced completely inside the machine and it is no longer necessary to set foot on the track. This leads directly to a crucial gain in safety for the operating staff on the machine and for the train traffic on the adjacent track. Indexing (releasing and re-tightening) and the replacement of the cutter inserts in the cassettes are carried out with robot support, also on the machine (Fig. 9).

The partial automation of the cassette replacement significantly increases safety, ergonomics and quality of the replacement process. It is no longer necessary to handle heavy loads (complete milling cutter). Furthermore, an external workshop or workshop container is no longer required, and the flexibility of the milling train is extended considerably with regard to the work site.

The workshop area is situated in the first section of the train. The second section of the machine houses, for example, the swarf bin and the polishing unit which is based on oscillating rubbing stones. This finishing technology generates a surface with very low roughness which meets all standards with regard to surface waviness and noise development (Fig. 10).

Another important point is the measuring equipment installed, to provide proof of quality, but also to provide a defined and documented condition of the rails which is a prerequisite for the successful implementation of a preventive maintenance strategy. In the case of the Japanese machines, the measuring technology was implemented by Vogel & Plötscher to record the cross and longitudinal profiles with utmost precision. Eddy current testing, as specified in Europe, was not required by the customers, but can be integrated into the machine concept.

A total of three rail treatment systems of the Romill type were ordered by the Japanese customers. These will initially be deployed on lines with mixed traffic. As these lines had never been machined before (not even with grinding technology), a regenerative strategy will be used initially before changing to a preventive strategy. The milling technology will also be used for prevention. The extension of the milling programme to conur-

Fig. 9: Robot support while replacing the cutter inserts on the Romill rail milling machine

Source: ROBEL

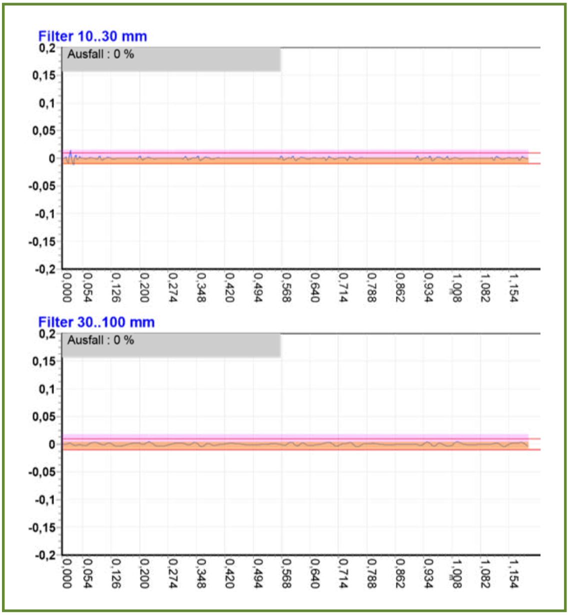

Fig. 10: Resulting surface with the lowest roughness after finishing with oscillating rubbing stones

Source: ROBEL

bations and high-speed lines is planned. The first of the three machines is already in Japan for commissioning and approval tests and will start working towards the end of 2021. Romill 2 and 3 will be delivered in summer and December 2021.

6.3 Urban milling with alternative drive

In addition to rail treatment systems for mainline railways, Robel and their partners are also working on a new technology concept for urban areas (suburban trains, undergrounds and trams). The Romill Urban rail milling machine is based on the proven SF04U milling machine by SBI. It has a very small structure gauge so that it even fits into the tunnels of the London Underground. The three-part vehicle concept permits machining of very tight curve radii. A fourth vehicle can also be added if customers require this. By adding this fourth vehicle, the material removal for each pass can be increased and/or a change in the rail profile can be accommodated without interrupting machining (Fig. 11).

The machine is equipped with the latest, purely electric milling technology which integrates the proven cassette design and optimised indexable cutter insert arrangement in a milling cutter with the usual diameter. Here, too, the focus is on ergonomics and safety for the operator during profile changes. Moreover, the milling units are equipped with an adaptive and balanced vertical guide which makes it possible for the first time to machine rails with a low track geometry quality. Up to now it has not been possible to implement this with conventional milling technology.

One of the greatest innovation steps is the implementation of the world's first hybrid drive concept for rail milling. The machine can be operated as usual as a diesel-electric machine. Furthermore, the vehicle is equipped with battery technology which enables purely electric rail machining for up to 3 hours. It is thus possible to work completely without emissions in tunnels and enclosed environments. The batteries are charged via external power sources or via the integral diesel generator. Based on this fully electric drive concept, implementation of an alternative power supply, for example a fuel cell, into the vehicle concept is possible with only little effort.

The Romill Urban also sets new standards in relation to finishing. The High Performance Polishing Process (HPP) will be used for the first time to generate a high-quality rail running surface optimised for noise. HPP combines the high speed of rotary grinding with the excellent surface quality achieved by polishing with oscillating rubbing stones. A new and completely non-sparking finishing technology is also under development. The first Romill Urban will be delivered early in 2022 and will be deployed in North America.

Fig. 11: Romill CMS3 rail milling train with hybrid drive during manufacture

Source: Schweerbau International

7 The correct technology for the matching strategy

To achieve the objective of maximum service life of the rails, a number of measures are available to the railway infrastructure manager, amongst which rail maintenance plays a central role. To produce a rail free from defects with the highest profile accuracy and acoustically optimised surface finish, the railway infrastructure manager can make use of various proven strategies and maintenance technologies. Strategically, preventive maintenance has proven itself, combined with regenerative interventions where the condition of the rail is no longer within the possibilities of prevention. Milling technology is increasingly being established as a complement to but sometimes also as replacement for conventional rail grinding. By combining strategy and technology in an optimum manner, it is possible to maximise the period of service of the rail system component and at the same time to reduce the life cycle costs to a minimum.

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Dr. Richard Stock
Global Head of Rail Solutions
Plasser American Corporation
rstock@plausa.com

Dipl.-Wirtsch.-Ing. (FH) Michael Seeleithner
Head of Sales
ROBEL Systems & Vehicles
Michael.Seeleithner@robel.com