60 years of modern ballast cleaning machines: state-of-the-art machine technologies for achieving an excellent ballast cleaning quality (Part 2 of 2)

The ballast bed is the load-bearing element of a railway track. Traffic loading subjects the ballast bed to static and dynamic stresses, causing ballast stone movement and wear that leads to fouling. Over time, the ballast bed can no longer adequately fulfil its load-bearing function, thus jeopardising track stability. The load-bearing function of the ballast bed can be restored by ballast cleaning. Part 1 of this two-part article, which appeared in the previous issue of this magazine, addressed research into ballast bed behaviour and the importance of ballast bed cleaning. Part 2 looks at state-of-the-art machine technologies that enable a high ballast cleaning quality to be achieved. In this respect, it addresses the main components of ballast cleaning machines and different machine configurations, as well as economical and ecological benefits of ballast bed cleaning.

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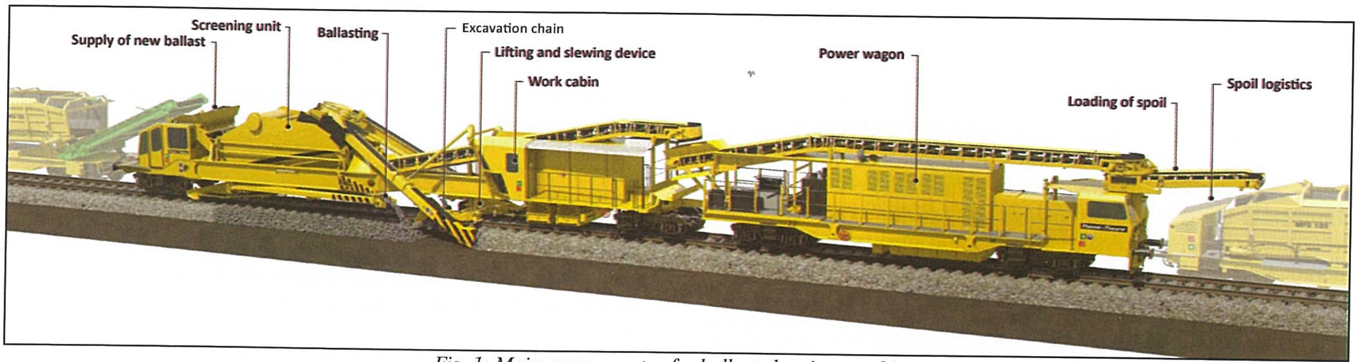

Fig. 1: Main components of a ballast cleaning machine

MODERN BALLAST CLEANING MACHINES: MAIN COMPONENTS AND THEIR FUNCTIONS

In Fig. 1, the main components of a ballast cleaning machine are depicted. Their respective functions are described in the following.

Ballast excavation chain – accurate removal of ballast bed material

Ballast cleaning machines, in addition to actually cleaning ballast, also have the task to ensure that the ballast bed has a clearly layered structure, and that the ballast layers are even and have a uniform thickness throughout. This is where the ballast excavation chain comes into play (Fig. 2).

The transverse cutter bar holding the ballast excavation chain can be precisely adjusted to the desired excavation depth and formation cross-fall – also during work. This ensures that an accurate even and straight cut of the track formation, both longitudinally and laterally, is achieved. The cutter bar prevents the excavation chain from sagging, so that no "water traps" can form. In a single pass, the track formation is prepared over the entire width of the ballast bed. Being able to adjust the excavation depth is also crucial for picking up the fine particles from the bottom of the ballast bed. The ballast excavation chain can achieve a depth of up to 1,200 mm.

For many years, the track formation was prepared longitudinally by manually controlling the excavation depth, with machine staff often eager to make "corrections". However, the longitudinal level of the track formation must be uniform and even, as otherwise the thickness of the ballast layers will vary.

Today, digital control systems ensure an accurate guiding of the cutter bar, which results in a perfectly even longitudinal cut of the formation.

The ballast excavation chain consists of scraper plates with two to six fingers, connecting links, and bolts. The fingers loosen the encrusted ballast material, which then falls onto the respective scraper plates of the ballast excavation chain and is conveyed directly up to the ballast screening unit.

Ballast screening unit: screen design – the key to success

Ballast cleaning machines are fitted with ballast screening units that have up to three vibrating screen decks. The most common mesh sizes adopted are 80/50/40 mm. However, it is the machine user/track owner who ultimately decides which mesh sizes are to be used. In Fig. 3, a three-deck ballast screening unit is shown.

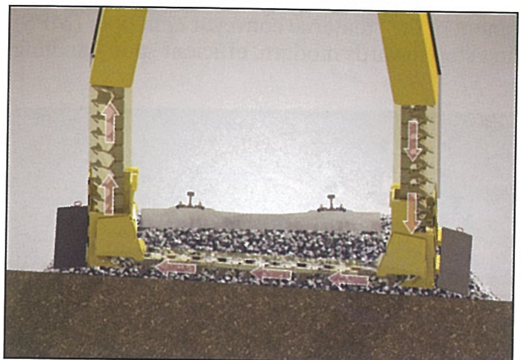

Fig. 2: Positioned under the track panel, the excavation chain produces a precise cut of the formation

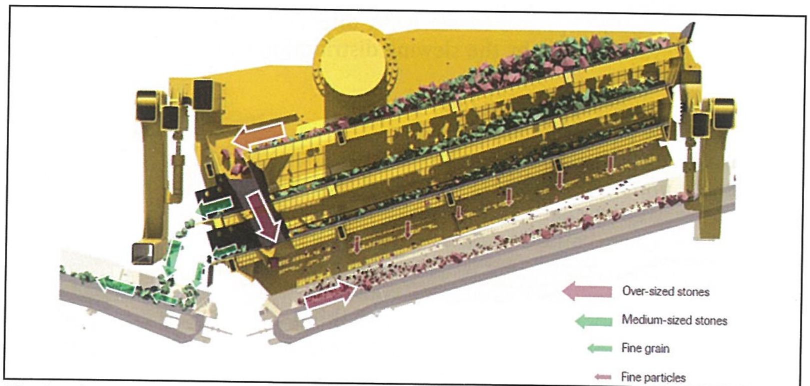

Fig. 3: Three-deck ballast screening unit

The top screen of a three-deck screening unit separates the over-sized stones which, via a chute, fall onto the spoil conveyor belt that takes them to material conveyor & hopper (MFS) units located at the front of the machine. The middle screen recovers the medium-sized stones, and the lower screen separates the remaining smaller stones from the spoil (fine grain). Like the over-sized stones, the fine grain material is also taken away on the spoil conveyor belt to the MFS units at the front of the machine (thus no spoil material can spill on the already cleaned ballast bed). A different conveyor belt conveys the recovered and re-usable stones to the ballasting unit. When working on superelevated track, the screening unit always remains in a horizontal cross-level position, which ensures an even loading of the screens.

Excellent ballast cleaning results

It is a fact that the better the quality of the recovered ballast is, the less frequently the ballast will have to be cleaned and tamped. Thus, the screening quality achieved is a decisive factor for the success of the ballast cleaning operation. As a rule, the screening results achieved by the ballast cleaning machines are excellent – the percentage of fine grain in recovered ballast is usually lower than in unwashed new ballast! Also, the recovered ballast has a better frictional behaviour, as the recovered stones do not break at the edges so much as new stones do.

In Austria, where mechanised ballast bed cleaning is conducted by track maintenance contractor companies, the acceptance process of Austrian Federal Railways (ÖBB) always includes an analysis of the recovered ballast. For instance, in 2018, the analysis results for all ballast cleaning sites yielded that every sample was within the tolerance range for new ballast as laid down in the relevant specification; this was also true for the percentage of fine grain permitted.

The screen width, the mesh size, the number of screen decks, the setting angle of the screen decks, as well as the frequency and amplitude of screen vibration determine the quality and performance of the ballast bed cleaning operation and are, thus, key to its optimisation. Especially the setting angle of the screen decks and the screen vibration parameters are crucial for achieving a high ballast cleaning quality.

Washing and crushing of heavily fouled ballast

For conditions in which the ballast stones are rounded and covered in sticky mud, e.g. in the case of a track formation that is rich in silt and clay, technologies to tackle this have been developed, such as star and finger screens, high-pressure wet-cleaning equipment (with integrated water-recycling), as well as crushing plants for sharpening the edges of the ballast stones.

Ballasting unit – high-quality ballasting

The cleaned ballast that has been conveyed from the screening unit to the ballasting unit by conveyor belt is transferred in measured quantities, via hydraulically adjustable baffle plates, onto slewing distribution conveyor belts that deposit it evenly over the entire width of the track formation, or in the zones required, directly behind the ballast excavation chain.

In fact, the ballast cleaning machines offer the following ballasting options:

- the entire ballast is placed in the track directly behind the ballast excavation chain by the slewing distribution conveyor belts; or
- the entire ballast is placed in the track directly at the screening unit; or
- a part of the ballast is placed in the track directly at the screening unit, and the rest is deposited directly behind the ballast excavation chain and/or to the sides of the track; or
- the above three ballasting options are adopted in combination.

A plough scraper located directly behind the ballast distribution unit removes any ballast that is present on the sleepers and the rails following ballasting and, at the same time, regulates the ballast crown.

A high ballast quality and an accurately positioned track are major prerequisites for opening the track to traffic again once the work has been completed. To this end, ballast cleaning machines can also be equipped with dynamic track stabilisation units to compact the ballast as soon as it has been inserted, thus securing the correct track geometry.

Integrated supply of new ballast

Ballast cleaning machines in every size category often feature an integrated supply of new ballast that is fed from a row of material conveyor & hopper (MFS) units located at the rear of the machine. Using these very much simplifies worksite logistics, as supplementary ballasting using separate ballast wagons is no longer needed, which also very much shortens the duration of track possessions. An integrated supply of new ballast also counteracts the shortage of ballast that usually exists at the beginning of work, as ballast is immediately at hand.

Track lifting and slewing device – exact guidance of the track during work

The track panel is not supported by the ballast while this is being excavated. Therefore, a track lifting and slewing device located directly in the vicinity of the ballast excavation chain provides the necessary support and guidance of the track panel during ballast excavation and removal. Roller clamps grip the rails by their head and continually guide the track panel – so that it does not deviate as regards longitudinal level and alignment – until the ballast has been re-inserted underneath the sleepers. Then, with the aid of the slewing device, the track panel is placed in the correct position.

As regards the latter, a track geometry measuring system measures and stores the original track geometry, i.e. prior to ballast bed cleaning, and the actual track geometry following cleaning – the exact positioning of the track panel is controlled by the stored surveying data and the manually entered correction values.

Cabins – staff safety during machine operations

Staff safety during ballast cleaning machine operations is of paramount importance. All the machine operating desks are located inside the cabins or in other safe locations on the machine, thus outside of danger zones. Video monitoring offers the machine operator an overview of all the important working areas. Further, the cabins are sound insulated and dustproof, which minimises the machine operator's exposure to noise and dust.

MFS units – efficient spoil logistics

In the early days of ballast bed cleaning, the spoil material used to be deposited to the side of the track and taken away later on. If workers failed to remove it, it made the embankments less stable or adversely affected drainage. Starting in the mid-1960s, dump lorries were used to transport the spoil load for load to a train consisting of low-sided open wagons. Also other complex mechanisms were adopted, such as conveyor belts that were put on top of open freight wagons, but this proved to be rather cumbersome and causing difficulties as regards unloading. All in all, these methods were not really suitable and also seriously impeded work progress.

The development of the "material conveyor & hopper (MFS) unit" was the first step towards modern, efficient spoil handling (Fig. 4).

Fig. 4: MFS units – efficiency in spoil logistics

The MFS units for spoil removal, which are coupled to the front of the ballast cleaning machine, have a moveable floor (a wide conveyor belt), on which spoil material deposited by the spoil conveyor belt of the ballast cleaning machine is transferred to the other end of the MFS unit, where it is picked up by another conveyor belt and dropped into the next MFS unit, and so on. In this manner, the MFS units, which are pushed by the ballast cleaning machine, are filled successively, from front to rear. As soon as several units are full, they are taken to a disposal site, where they are emptied and then immediately returned to the worksite, where they are filled again with material collected by the MFS units that remained at the worksite, and so on. The entire spoil logistics takes place on the track under repair, thus without hindering traffic on the adjacent track.

Control technology and automatic filling device

MFS units of the latest generation are equipped with a central process control system featuring a programmable logic controller (PLC), which allows all MFS operations to be controlled from a single cabin (e.g. the main cabin of the ballast cleaning machine) – there are no operators present on the individual MFS units. An automatic filling device, with the aid of sensors that scan the inside of the MFS hoppers, ensures that the MFS units fill up continuously and evenly. This, in combination with the machine control system, allows automated loading/unloading of entire MFS consists.

Machine output – a powerful performance offered by modern ballast cleaning machines

The work output of a ballast cleaning machine is measured in m^3/h of excavated and screened ballast material. This output ties in directly with the performance of the ballast excavation chain and the screening unit.

There are two calculation methods for determining work output:

- *Method 1* – the volume of ballast material that was in the track prior to cleaning forms the basis for calculation: the ballast cross-section in m^2 is multiplied by the progress made by the machine in m/h – then, from the outcome in m^3, the respective sleeper volume is deducted;
- *Method 2* – the volume of ballast and spoil material that comes out of the machine forms the basis for calculation: the same calculation method as that for Method 1 is applied but, in order to take into account the loosening of the material when it passes through the machine, a swell coefficient is added (usually 30%).

In this article, the work output noted is based on Method 1.

Machines produced around 1960 achieved a work output of approx. 100 m^3/h. Today's machines with a single multiple-deck screening unit have a capacity of up to 700 m^3/h – this is the maximum output whereby, for a machine with a single screening unit, a high cleaning quality is guaranteed. Only machines with multiple screening units can achieve higher outputs. On many high-capacity railway lines, it is today common practice to use machines with two screening units, which can achieve a work output of approx. 1,000 m^3/h.

Further options for increasing work output include the adoption of machine systems with three screening units and two ballast excavation chains, or using a combination of a ballast excavation chain and a shoulder excavation unit with a total of four screening units. In fact, today, ballast cleaning machines come in various designs and sizes, as also alluded to in the following.

MODERN BALLAST CLEANING MACHINES AVAILABLE IN VARIOUS DESIGNS AND SIZES

In 1961, Plasser & Theurer introduced its first ballast cleaning machine, the fully hydraulic RM 61. With it came a now 60-year period of ongoing machine development and innovation, which has culminated in the complex machine systems that are in operation today.

To meet various requirements, ballast cleaning machines of different designs and sizes are nowadays available [1], see also the examples shown in Fig. 5. As not every ballast cleaning machine is suitable for all purposes, the company responsible for machine deployment should take the following factors into consideration: the size of the worksite (e.g. track lengths), the number and duration of track possessions, as well as the estimated degree of ballast bed fouling.

Important factors when selecting the most suitable design and construction of ballast cleaning machines to be adopted include:

- the minimum distance between track centres;
- the maximum track gradient;
- the minimum machine action radii in curves;
- the maximum vehicle loading gauge;
- the maximum machine operating clearance;

as well as the prevailing limitations that the machine is subject to when working on the track.

Ballast bed cleaning systems for an enhanced use of track possessions

A prerequisite of track maintenance efficiency is an optimal use of track possessions, which can be effected by deploying modern machines featuring state-of-the-art technologies. This is also true for ballast bed cleaning, as alluded to in the following.

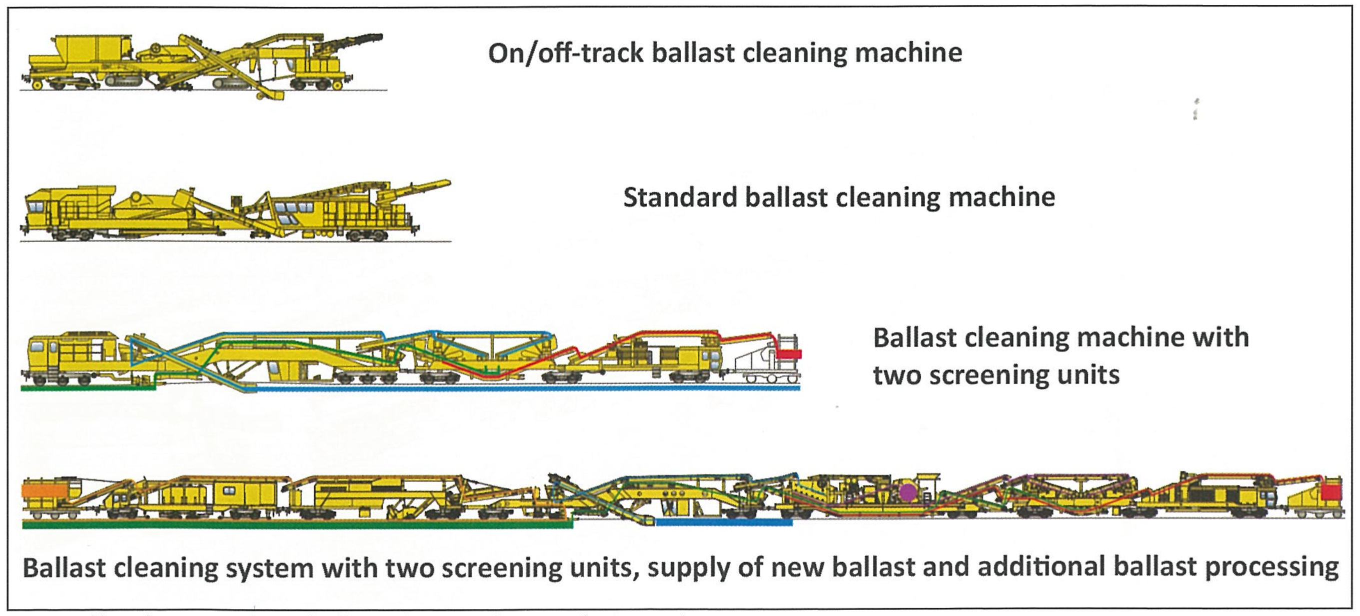

Fig. 5: Ballast cleaning machine of different designs and sizes – a basic overview

Compact powerful machines – RM 80 set the standard for modern ballast cleaning machines

In 1980, Plasser & Theurer introduced the RM 80 machine series of compact design which, featuring one ballast excavation chain, a single screening unit and an output of 700 m^3/h, set the standard for high-quality ballast bed cleaning and served as the prototype for modern ballast cleaning machines (Fig. 6).

To meet the demand for higher outputs (up to 1,000 m^3/h), machines featuring two screening units were introduced, with the machines of the RM 800 series being the first of this kind. Over the years, Plasser & Theurer developed these machines further fitting them, for instance, with integrated dynamic track stabilisation units.

Machines with two screening units and integrated supply of new ballast

Plasser & Theurer also offers complex ballast cleaning machines that feature two screening units and an integrated supply of new ballast which, apart from cleaning ballast, ensure that the ballast bed has a uniformly layered structure with both cleaned and new ballast. Their integrated dynamic track stabilisation unit ensures the compaction and, thus, homogenisation of each individual ballast layer. These machine systems can achieve an output of 1000 m^3/h and more, as well as a very high performance during very short track possessions (e.g. three hours per night in France (Fig. 7)). Machines of this kind are also deployed as part of complex machine systems for large-scale ballast cleaning operations, such as the "High Output Ballast Cleaning System (HOBCS)" in Great Britain [2]. Using these machine systems, the track can be opened to traffic immediately following the end of the track possession.

Ballast cleaning machines with two ballast excavation chains and three screening units

Adopting machine systems with multiple ballast screening units allows an optimal use of track possessions to be made. The RMW 1500, for instance, is a machine with three screening units and two ballast excavation chains, which allows a larger excavation depth and, thus, a larger amount of ballast material to be picked up for cleaning – this significantly reduces the amount of new ballast required. This machine, which can achieve an output of up to 1,500 m^3/h, has been in very successful operation in Germany.

Combination machines – simultaneous ballast bed cleaning and track renewal

Track renewal and ballast bed cleaning are nearly always carried out as a joint project, so that the new track can be laid on a perfect ballast bed. The RU 800 S is the world's first combination machine for continuous-action track renewal and simultaneous ballast bed cleaning with supply of new ballast [3], which allows

Fig. 6: Following in the footsteps of the RM 80 – the RM 85-750 MFS, featuring one ballast excavation chain and one screening unit

Fig. 7: The RM 900 HD high-output ballast cleaning machine with two screening units and integrated supply of new ballast

these tasks to be performed in a single track possession – this optimal use of track possessions results in lower operation hindrance costs. Two further machines of this kind were put into operation in 2019 (Fig. 8), one of them in France.

On/off-track ballast cleaning machines

Machines that can work off-track, on sections with dismantled track panels or removed turnouts, were around when on-track ballast cleaning machines were first introduced. Starting in the 1960s, these types of machine became less popular owing to the success of on-track ballast cleaning machines. Nevertheless, on/off-track ballast cleaning machines are still in use today, especially in station areas and turnouts, where they are deployed in combination with on/off-track MFS units.

Turnout ballast cleaning machines: no dismantling of turnouts required

In turnouts, the width of the area from which ballast has to be excavated constantly changes where the tracks diverge. This means that the width of the ballast excavation unit must be adjustable.

Fig. 8: The RU 1000 S combined track renewal & ballast cleaning machine

In 1974, Plasser & Theurer introduced its first ballast cleaning machine for turnouts: the RM 74 U, which solved the issue of an adjustable width, as its cutter bar could be gradually extended to a length of 7.7 m.

The more modern solution (URM 700-2) is to slew the cutter bar underneath the track panel at the required excavation depth, whereby the slewing angle determines the excavation width – without requiring any dismantling of the turnout or digging of an access hole (Fig. 9). This capability of fast insertion and removal of the cutter bar significantly reduces the time needed for ballast bed cleaning in turnouts, and also allows the machine to work cost-efficiently on short track sections [4].

Fig. 9: Non-stop through turnouts (URM 700-2) – no track panel dismantling or access hole digging required

TRACK FORMATION REHABILITATION – ENHANCING BALLAST BED PERFORMANCE

The ballast bed can only perform its technical function if the load-bearing capacity of the track formation is sufficient. If this is not the case, a formation protective layer (FPL) must be inserted [5]. By inserting a layer of fine gravel of a particular specification in combination with geotextiles, penetration of the ballast bed by solid particles that rise from the mud is prevented and lateral drainage promoted, which increases the load-bearing capacity of the track formation – this method has proven to be very effective.

When the process of inserting formation protective layers was first introduced, it was done using the cut-and-cover method, a technique adopted in road construction, which considerably extended the duration of track possessions. For this reason, an alternative on-track method was sought. The first development in this direction came in 1967: ballast cleaning machines that could insert protective layers of fine gravel and geotextiles – as these layers had a maximum thickness of only 10 cm, in today's terms, they would be described as mere "support layers".

In 1983, the first dedicated on-track formation rehabilitation machine, the PM 200, went into operation. Ten years later, the developments that make up today's methods came into being, which allow the ballast material that is excavated from underneath the track panel to be processed within the machine and then to be re-inserted into the track either in part or in full.

Today's state-of-the-art formation rehabilitation machines can also conduct ballast bed cleaning (Fig. 10), as well as (optionally) integrated washing and crushing of ballast stones – a description of various methods that follow this approach can be found in [6].

Formation rehabilitation results in a highly sustainable track geometry. In Austria, for instance, following a track formation rehabilitation campaign that was conducted in 1997, it took six years before tamping became necessary for the first time and then, in 2008, only some short track sections needed tamping again – it was not until 2015 that a full tamping campaign of the entire track length was necessary [7].

BALLAST BED CLEANING – ECONOMICAL AND ECOLOGICAL CONSIDERATIONS

High-quality ballast bed cleaning leads to a clear increase in track quality with inherent economical and ecological benefits, as alluded to in the following.

Fig. 10: RPM RS 900 formation rehabilitation machine with two ballast excavation chains and integrated ballast recycling – can work as a stand-alone ballast cleaning machine (picture also shows FPL insertion)

Ballast bed cleaning – a matter of cost efficiency

The quality of the ballast bed is a major determining factor for track quality – a clean ballast bed is a major prerequisite for this.

Delaying ballast bed cleaning leads to higher track maintenance costs, speed restrictions, as well as a shorter service life of track components. The resulting costs can easily get out of control. For instance, if it becomes necessary to impose speed restrictions, in order to maintain safe rail traffic operations, or if an unscheduled full track closure is needed to quickly carry out an exchange of the entire ballast bed. Or the costliest option in the world of track: if a complete track renewal needs to be carried out prematurely due to a shortened service life of the track.

Ballast material is an expensive commodity. High-quality ballast cleaning makes it possible to increase the amount of ballast that can be re-used. Furthermore, as a cleaned ballast bed contains fewer fine particles this increases the service life of the ballast.

Economic efficiency of ballast bed cleaning – a simple assessment

Model-based calculations have shown that ballast bed cleaning is economically efficient up to almost 70% of the strategic service life of the track, provided that the other track components do reach their estimated service life. In the case of maintenance-intensive turnouts, conducting a ballast cleaning operation after 70% of the strategic service life has passed can still be economically viable [8].

Ballast bed cleaning achieves a significant and sustainable improvement of all relevant track parameters, as has been proven time and time again. In most cases, the track geometry quality produced corresponds to the initial track quality. Based on recent measurements conducted by Austrian Federal Railways (ÖBB), this high level of track geometry quality remains practically unchanged – requiring no tamping – for at least three years.

Ballast bed cleaning – ecological benefits

Depending on track type and track spacing, it takes some 3,000 to 5,000 m^3 of ballast to produce a single kilometre of double-track railway line. Such quantities of ballast require an optimal use and cost-efficient handling of material resources, in order for this to be eco-friendly. This is why timely ballast bed cleaning also means using track material resources sparingly – doing so extends their service life. Also, a clean ballast bed results in a reduction of structure-borne noise.

Example of excellent results achieved

For many years now, for the evaluation of the cost-efficiency and sustainability of maintenance measures, ÖBB has adopted a monitoring programme that assesses the success of respective measures and, thus, also as regards the impact of ballast bed cleaning on track geometry sustainability.

If a technically flawless ballast bed cleaning does not result in a long-term improvement of the track geometry, this may typically be due to poorly executed preparatory work and dysfunctional drainage [9].

Maintaining or restoring drainage of the track ensures that the track can fulfil its technical function.

Ballast cleaning is not complete unless it effects that precipitation is reliably directed into railway ditches and subsequently into receiving waters. Removal of debris jams and shrubbery that block waterways is integral to ballast bed cleaning.

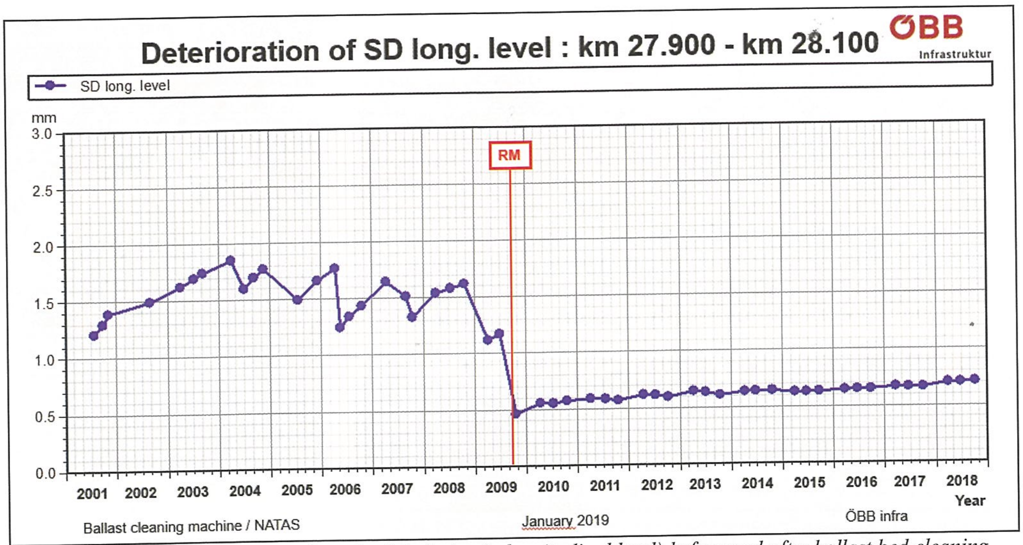

Fig. 11: Track quality progression (standard deviation in longitudinal level) before and after ballast bed cleaning

Ballast bed cleaning is normally so successful that the track will not need any maintenance for several years as exampled by Fig. 11, which shows the progression of standard deviation in longitudinal level of a 100 m track section over an 18-year time period.

As can be observed from Fig. 11, between 2001 and 2009, track maintenance was conducted frequently and the standard deviation varied between 1.2 mm and 1.8 mm. Following ballast bed cleaning in 2009, the standard deviation was 0.5 mm. In 2018, it was still a mere 0.7 mm. This graph clearly demonstrates that ballast bed cleaning leads to a sustainable improvement of the track geometry.

FINAL REMARKS

Ballast bed cleaning is a core technology integral to track maintenance. Delaying ballast bed cleaning leads to higher track maintenance costs, speed restrictions, as well as a shorter service life of track components. The resulting costs can easily get out of control. The state-of-the-art machine technologies described in this article allow an excellent quality of ballast bed cleaning to be achieved in a technically correct, cost-efficient and eco-friendly manner.

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Plasser & Theurer machine servicing packages

It is of great importance that heavy-duty track maintenance machines are in an overall good working order, in order to ensure their availability, as any machine breakdown would result not only in costly machine downtimes, but also higher track hindrance costs as a result of longer track possessions. Machine servicing performed by highly trained and qualified staff that have the know-how and expertise to maintain these very sophisticated high-tech machines is therefore essential.

Plasser & Theurer offers the following four machine servicing packages:

— *all-inclusive servicing – full servicing at a fixed price:* this package, which is aimed at clients wishing to have a fixed annual budget for machine servicing, entails routine monthly and annual servicing, as well as servicing and repair as and when the need arises. The fixed price also includes spare and wear parts, as well as the exchange of all filters, oils and lubricants as defined in the machine maintenance manual. It further includes inspections, which are usually performed every six years, and the servicing and overhaul of main machine work units (tamping units, lifting and lining units, ballast excavation chains, ballast screens, and the like). The all-inclusive servicing package covers either the entire service life of a machine or a specified time period;

— *basic servicing – regular servicing at a fixed price:* this package, which includes the servicing defined in the machine maintenance manual, is performed semi-annually and/or annually. It covers the inspection of the machine operating systems, as well as the regular calibration and validation of measuring systems.

Further, it entails inspections based on the VEDO principle and the provision of corresponding audit reports, including a list of any spare parts needed.

An advantage of the basic servicing package is that Plasser & Theurer service staff are a direct point of contact, offering support as and when needed. The defined fixed price covers all work performed;

— *inspections – an ideal start:* this package, which is the lean solution for minimising the risk of machine breakdowns and maximising machine availability, includes routine machine inspections by Plasser & Theurer service technicians, either directly at the worksite or the machine workshop. The documentation process follows the standardised VEDO principle. An audit report is provided, as well as a list of any spare parts needed.

The inspection servicing package entails the provision of all the information a client needs to preventatively exchange machine parts;

— *technical support – assistance as and when needed:* this package allows the client to count on Plasser & Theurer service technicians whenever and wherever needed. Machines will be serviced on scheduled dates and also if there is an emergency. Small repairs will be performed immediately to restore machine operability. The technical support package can be supplemented with that of inspections, as well as that of basic servicing.

The four machine servicing packages are available for single machines, as well as entire machine fleets, around the globe.