

## Criteria for cost-effective ballast cleaning: machine design considerations

Traffic and a number of environmental influences cause the track to age. Even track that is used only scarcely, or not at all, would increase in entropy due to the general tendency in nature that highly organised systems transform into less organised ones. Particularly, fouling of the ballast bed leads to a reduction in track geometry stability and quality, which results in the need for maintenance to be carried out at ever shorter intervals. Timely ballast cleaning and, if needed, measures to improve the subgrade are the strategies to be adopted here.

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The need for ballast cleaning can be recognised immediately on the basis of inspections using track recording cars, equipped with suitable analysing systems. Investigations using Geo-Radar measurements provide a quick insight into the lower layers of the ballast bed. Direct appraisal of the state of the ballast by taking samples is the safest criterion. Samples can be taken either manually or - far more economically - by using a probing device to obtain boring cores from the track, such as the subsoil probing machine (UUM) (Fig. 1). When, by screening the material, it is found that the fouling of the ballast has reached over 30% in weight, the ballast bed should be cleaned.



Fig. 1: The UUM subsoil probing machine, featuring three boring units for taking boring cores from the track

### BALLAST CLEANING MACHINES (Fig. 2)

Ballast cleaning machines perform the most arduous work in the track maintenance sector. The continuous removal of the ballast bed material from the track and the working thrust needed for this, the transport of several tons of material within the machine, the screening process, the returning of the cleaned material, as well as the removal of spoil, require huge traction forces.

In 1959, Plasser & Theurer brought its first ballast cleaning machine onto the market that worked off-track which, in late 1962, was followed by its first fully hydraulic on-track machine.

With increasing mechanisation of track maintenance work, it became more and more necessary to coordinate the ballast cleaning machines into overall technologies. In particular, working in conjunction with track renewal trains demanded far higher outputs from ballast cleaning machines.

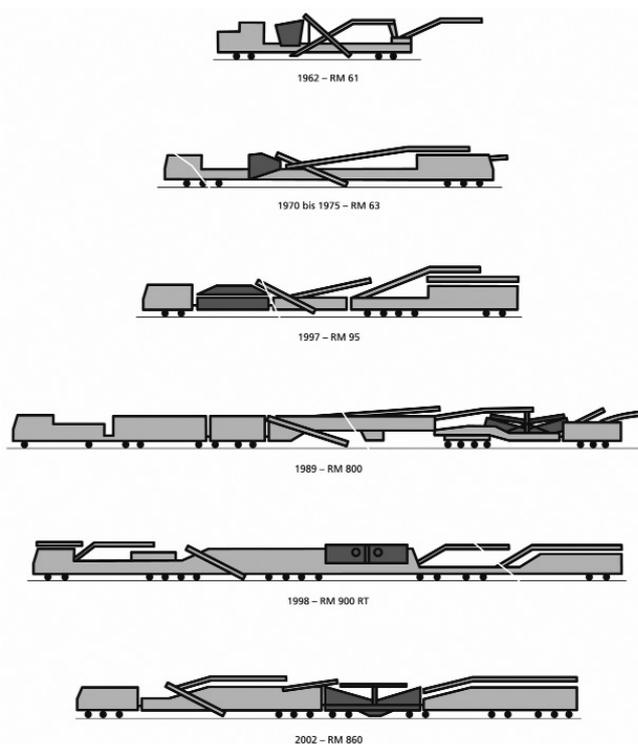


Fig. 2: Design developments of Plasser & Theurer ballast cleaning machines

The first ballast cleaning machines, developed by Plasser & Theurer, to meet these higher outputs were the machines of the type RM 63, equipped with a large-dimensioned excavation unit and a single screening unit. Between 1970 and 1975, several machines of this type went into operation in France and Germany. However, these compact six-axle machines which, featuring a total mass of 120 t, an engine output of around 520 kW and a nominal output of 650 m<sup>3</sup>/h, are still operating today, reached the limits of the desired capacity.

New ways had to be found to achieve extensive increases and appropriate reserves of output. Thus, in the 1980s, machine designs were developed that guaranteed a 100% increase in output. The main feature of these designs was the introduction of a double screening unit. All machine components, particularly the size and speed of the ballast excavation chain, and the screening unit, have to be designed to meet the high output.

### Ballast excavation chain

On modern heavy-duty ballast cleaning machines, the excavation chain takes the ballast bed material, via chain guides, not directly to the screening unit - as was the case on the earlier ballast cleaning machines - but via a collection hopper on a conveyor belt unit, from where it is supplied uniformly to the double screening unit. The formation that is produced during excavation is an important feature. There should be no “water traps” either in longitudinal or lateral direction (Fig. 3), and the resulting formation should have the correct cross-fall, in order to allow any water entering from above to flow away.

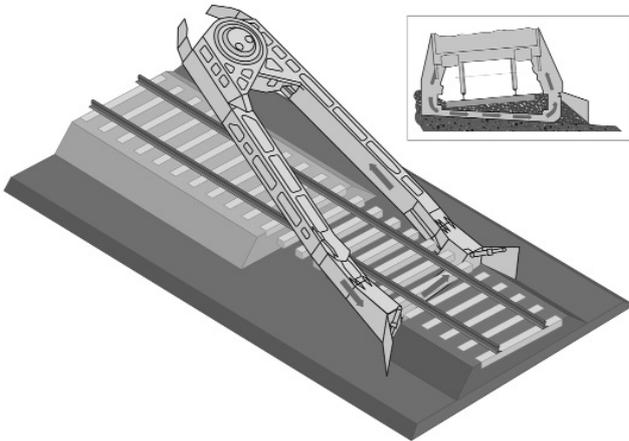


Fig. 3: Ballast excavation has to be performed absolutely uniformly, in both the lateral and the longitudinal direction, so that no “water traps” occur and the resulting formation has the correct cross-fall, thus allowing any water entering from above to flow away

The output of a ballast cleaning machine depends primarily on the advancing speed and the height of the excavation chain, or the excavation depth. The volume output of the machine is simply the forward speed multiplied by the excavated cross-section (output = forward speed x cross-section). With the usual excavation depths, the quantity of material is mostly around 2 m<sup>3</sup>/m. The shovel size or the cross-section of the chain guides, the spacing between the chain shovels and the chain speed define the quantities of material that is taken away (shovel cross-section x chain speed). The maximum chain output lies slightly under 1000 m<sup>3</sup>/h.

However, at high chain speeds, besides an increase in noise emissions, the following problems may arise:

- an over-proportional increase in the wear of the excavation chain (Fig. 4). The wear of the chain links and of the wear plates increases progressively. For instance, a 10% rise in chain speed results in a wear increase of 15-20%. To reduce this problem, the chain links are made of highly wear-resistant manganese hardened steel. By altering the alloying constituents, the service life has increased considerably over the past years (Fig. 5). The service life of the excavation chain has also been increased by using a special constructional feature, whereby hardened chain bolts are supported in pressed-in bushings in the connecting links which, if required, can be reconditioned (Fig. 6);
- material could fall back into the track, thus not reaching the collection hopper, which then has to be taken up again.

Based on experience gained to date, the chain speed should be no more than 3.5 m/s.

### Screening unit

The better the quality of the screened material, the less frequently the ballast requires cleaning and tamping. The quality of the screened material has to be as high as possible. Modern high-capacity ballast cleaning machines are equipped with a double screening unit, offering a cleaning capacity of 1000 m<sup>3</sup>/h and more, and a machine output of 500 m<sup>3</sup>/h and higher.

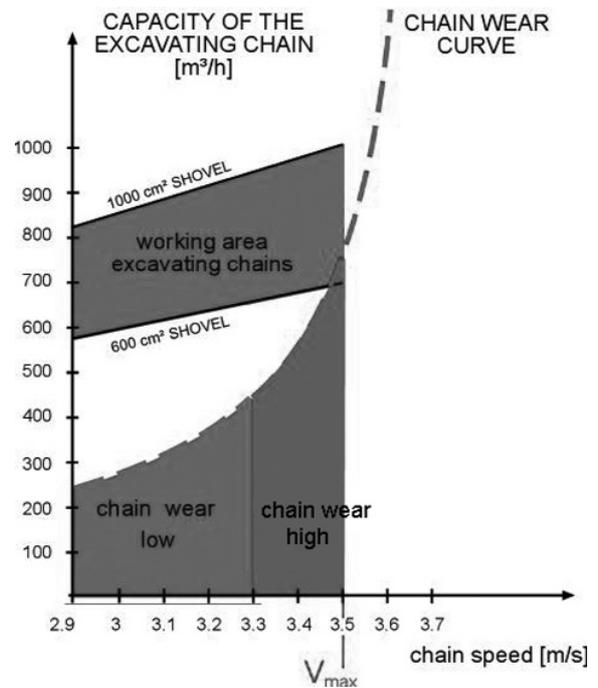


Fig. 4: Chain wear curve and conveying capacity of the ballast excavation chain (see [Ref.])

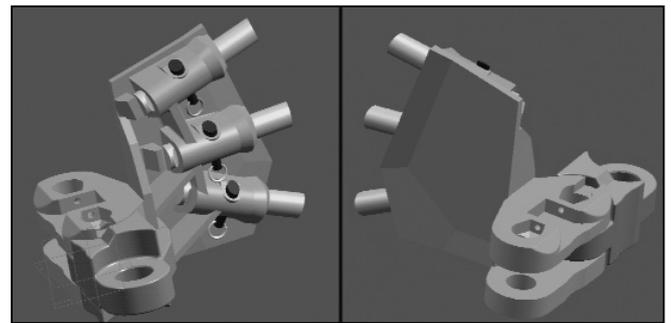


Fig. 5: Ballast excavation chain featuring three adjustable scraper fingers; the chain links are made of high-alloy steel

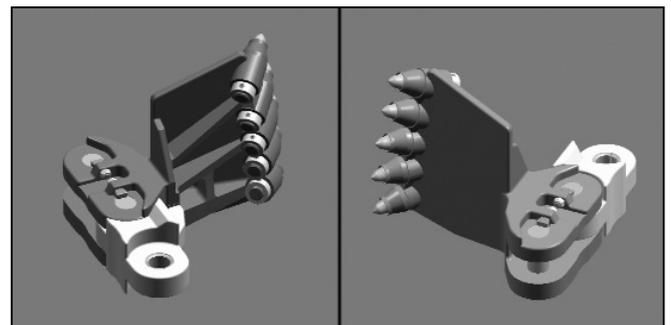


Fig. 6: The five easily exchangeable scraper fingers of this ballast excavation chain are designed as specially armoured round shaft chisels. The chain links feature pressed-in bushings

An optimisation of the screening unit of a ballast cleaning machine with respect to cleaning quality and output requires the addressing of the following parameters:

- *the size of the screen surface*: the full extent of the screen surface has to be able to easily handle the separation of spoil and ballast, thereby ensuring the quality of the reclaimed ballast. When cleaning the ballast bed, all excavated material should be conveyed to the screening units, in order to achieve a high recycling effect. Although the use of a preliminary filter could raise the advancing output of the machine, the effect of a ballast cleaning machine would be lost, as the material would be separated without treatment.

The size of the screen surface is, to a large extent, limited by the clearance gauge and the setting angle of the screen. In Fig. 7, the fundamental correlation between the setting angle of the screen and the possible output per square metre of screen surface is shown. The smaller the screen angle, the lower the screening output.

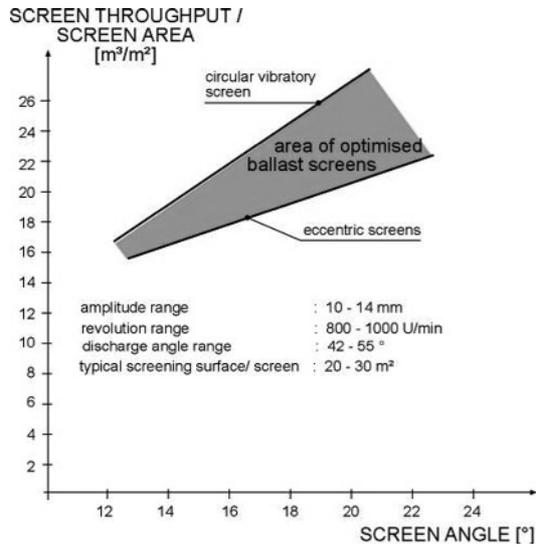


Fig. 7: Influence of the setting angle of the screen on the screening performance (see [Ref.] )

Plasser & Theurer ballast cleaning machines are characterised by the following cleaning outputs:

- the RM 80 ballast cleaning machine, which features a single screening unit with a screen surface of 30 m<sup>2</sup>, offers a cleaning output of 550-600 m<sup>3</sup>/h;
- the ballast cleaning machines with double screening units, such as the RM 801, the RM 900 and the RM 2002, have a screen surface of 2 x 23 m<sup>2</sup> and offer a cleaning output of 1000 m<sup>3</sup>/h;

- the RM 860 ballast cleaning machine, which features a double screening unit with a screen surface of 2 x 25 m<sup>2</sup>, offers a cleaning output of 1000-1200 m<sup>3</sup>/h (Fig. 8);
- *the number of screen decks*: Plasser & Theurer ballast cleaning machines are equipped with screening units that feature three screen decks (Fig. 9), whereby the upper screen deck has the function of eliminating the over-sized ballast stones. The medium-sized and small-sized stones are reclaimed from the material, and separated from the spoil, which reaches the middle and the lower screen decks, respectively. The flow of material over three screen decks guarantees a thorough separation of re-usable ballast from the spoil. As a result, after ballast cleaning using modern high-capacity machines, the portion of fine particles in the ballast bed is lower than with new ballast, which means a higher quality of the ballast bed material;

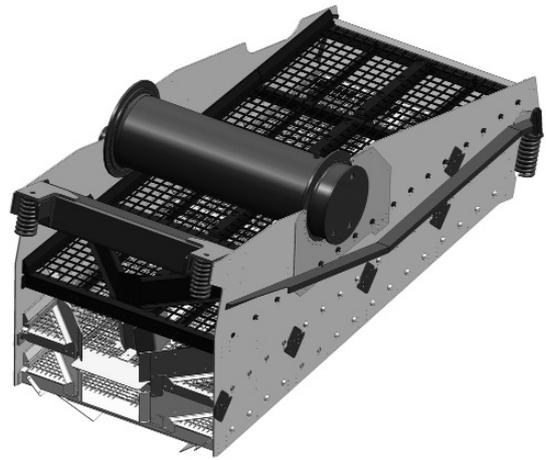


Fig. 9: Diagram showing a three-deck screening unit

- *the mesh size*: for achieving grain of Class 1, the standard mesh sizes of the three screens are, from top to bottom, 80/50/30 mm;



Fig. 8: Double screening unit of the Plasser & Theurer RM 860 ballast cleaning machine

— *the direction and frequency of screen vibration*: the vibration of the screens is an important factor for achieving a good cleaning quality, whereby the direction of vibration is of importance. The screens, in conjunction with vibration, achieve a higher cleaning effect as, due to the pulsing acceleration of the ballast stones, the spoil is loosened from the stones. The vibration also causes a good distribution of the material on the screen grids and a thorough separation of spoil and ballast (Fig. 10). The direction of vibration is effected by:

- linear oscillators which, through opposite-motion flyweights, retain only one direction of screen vibration. The direction of vibration - the discharge angle - can be set exactly;
- eccentric oscillators, which produce a constant circular oscillating movement of the screening unit. As this oscillation system operates independently of load, it is predestined for high-volume output operation or when there is a fluctuating supply of material. Eccentric oscillation screens have a high self-cleaning capability. The eccentric drive with counterweights produces a complete balancing of masses during operation and, thus, exerts low dynamic stresses on the machine construction.

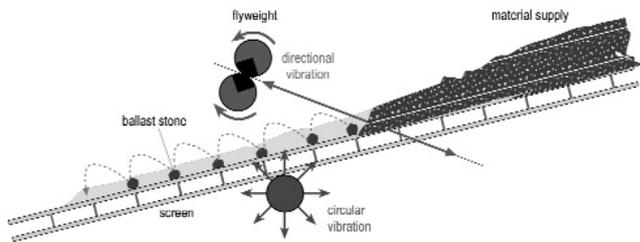


Fig. 10: Screen vibration (directional and circular) has an influence on the distribution of material. By producing an acceleration of the ballast stones, a better distribution of the material onto the screen decks is achieved, as well as a more thorough separation of spoil and ballast

The frequency of the screen vibration has an influence on the screening output. With a screen vibration frequency of 30 Hz and an average contact time on the screen surface of circa 3 seconds, the material being screened undergoes about 100 acceleration pulses. Thanks to the high average contact time on the screen surface, an excellent cleaning effect is achieved.

It is an absolute necessity that high-performance ballast cleaning machines are designed, from the outset, for the desired output capacity. Later increases in output will be at the expense of the cleaning quality (when machines with a low-rated output drive at a high rate of revolutions, the screen throughput will increase and the contact time of the material on the screen surface will be reduced substantially, leading also to a drastic reduction in the cleaning effect);

- *the setting angle of the screens*: on Plasser & Theurer ballast cleaning machines, the setting angles of the screens range between about 10° and 20°. Eccentric oscillation screens can be set somewhat steeper. This means that the performance is somewhat higher. Generally, however, the cleaning quality is higher when the screen is flat. In other words, a steeply adjusted screen can achieve higher outputs, but only with a poorer result of the screening quality.

A recently introduced technology to raise both screening output and quality is the application of a grid screen, whereby metal bars (grids) are positioned in a cascading fashion (Fig. 11). The material being cleaned is set into an additional oscillating movement by the grids, and this reverberation (like a tuning fork) achieves an additional cleaning effect;

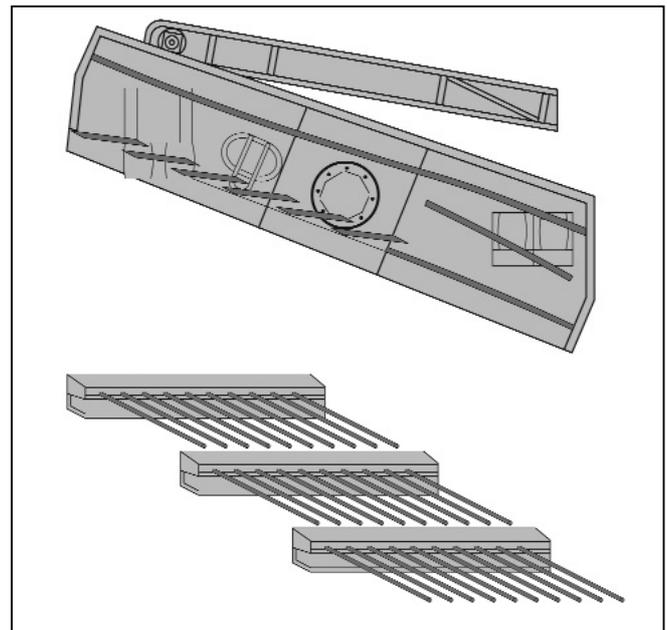


Fig. 11: A grid screen inside the screening unit, consisting of metal bars positioned in a cascading manner

- *the supply of material to the screening unit*: on the Plasser & Theurer ballast cleaning machines of the first generation, equipped with a single screening unit, the excavated ballast material was supplied directly from the excavation chain, via the chain guides, to the screens. On the modern high-capacity machines, equipped with a double screening unit, the excavated ballast material is first passed on to an intermediate collection hopper, from where it is taken, via conveyor belts, to the two screening units.

Transportation from the intermediate collection hopper to the double screening unit, via conveyor belts, means that the belts are well filled and offer a wide supply of material to the screens. Thus, a high efficiency of the screening unit is achieved, as all parts of the screens, over the entire width, are utilised. A further hopper behind the screens has the function that when the machine is shut off and the screens run on for a few seconds, the material still present on the screens can be collected and stored.

The conveyor belts of high-capacity machines have to have a sturdy design and should not be friction-powered. Therefore, hydraulically-powered conveyor belts are used which, together with the fact that the overall machine is hydraulically driven, enable a stop-and-go operation. When, during ballast cleaning the machine stops due, for instance, to the presence of over-sized obstacles in the ballast bed, the ballast material present on the machine should not simply be passed on. Conveyor belts and screens are switched off. The material remains in the hoppers and conveyor units of the machine. Otherwise, irregular heaps of material would occur and, if work were continued, the next sections to be worked would be characterised by a surplus and lack of ballast.

The hydraulic drive and the structural design of the conveyor belts have proven to be reliable when re-starting. There is always about 12 m<sup>3</sup> of ballast material on the machine which, depending on the degree of fouling, consists of about 4 m<sup>3</sup> of spoil and 8 m<sup>3</sup> of reclaimable ballast. After a machine stop, a hydraulically-powered machine can get all systems going again when re-starting, which is not necessarily guaranteed in the case of electric drives.

#### Modular design of the modern high-capacity ballast cleaning machines

The first generation of Plasser & Theurer ballast cleaning machines had a compact design, featuring a long spoil conveyor belt, with a length of about 10 metres from the pivot, which could be slewed. Thus, for transfer travel, a match wagon was needed.

The demands for increasing outputs resulted in the ballast cleaning machines becoming bigger and bigger in size, calling for a multi-sectional machine design. Overall machine mass also increased, with ballast cleaning machines designed during the past 20 years featuring a total mass of between 220 and 280 t, 10 to 17 axles, and an overall engine output, which is equivalent to the required output, of up to 1500 kW. The ballast cleaning machines of the later generations, thus, feature a modular design, consisting of an excavation section and a screening section, usually, with separate drive units. With only a single exception (the Plasser & Theurer RM 802), the basic concept is such that the spoil is transported to the front. Should any spoil be lost during this process, it would be picked up by the machine and separated again in the screening unit. On several machine designs, new ballast can be supplied from the rear and installed by the machine, either separately or together with the reclaimed old ballast, whereby the height of the track can be regulated exactly.

The modular design of the ballast cleaning machines has the advantage that additional technologies can be built onto separate vehicle components and incorporated into the machine configuration, such as the application of star screens, a high-pressure ballast washing plant, including a water-recycling system, a crushing plant to sharpen the ballast stones, as well as other technologies, all aimed at increasing the cleaning effect even further.

Using wet cleaning of ballast, it is possible to reclaim a considerable quantity of ballast bed material. In Fig. 12, the correlation between the moisture content of the screened material and the possible screening output is shown. As can be observed, when there is a high proportion of clay or loam, the screening output is greatly reduced, even when it has a relatively low moisture content (between 5 and 10%). Whereas, if it has a high moisture content, the cleaning effect increases again.

To reduce the formation of dust in the ballast excavation area, some ballast cleaning machines are equipped with a tank wagon and a dust arresting atomiser unit. Ballast cleaning machines are sometimes also fitted with ballast consolidating units, by means of which ballast is brought into the area around the sleeper ends, enabling the track to be embedded firmly in the cleaned ballast bed. A sweeper unit can also be fitted to sweep excess ballast from the sleepers, as well as equipment to place geotextiles, membranes or insulating slabs.

### Measuring equipment

The excavation equipment of the ballast cleaning machines needs to be controlled in the longitudinal direction, in order to ensure consistent ballast conditions. In the same way, the cross-fall of the formation produced has to be geometrically perfect, in order to guarantee that any surface water can flow off. The excavation depth also has to be controlled, so that no soiled layer of ballast remains on the formation, as this would hinder the drainage of surface water. A wet layer would soften the track formation and, thus, reduce its bearing capacity.

Thus, the modern ballast cleaning machines are equipped with measuring and regulating systems which, together with a personal computer suitable for the rugged working conditions of maintenance machines, enable automatic control of the excavation depth and other parameters. There are cable and phase-angle sensors, an electronic pendulum, etc., mounted on the machine that control all the required parameters. An external laser reference plane can also be used to control the excavation depth.

An electronic recorder-plotter is used for quality control of the work performed, whereby up to six parameters, e.g. excavation depth, formation cross-fall and track lowering, are recorded.

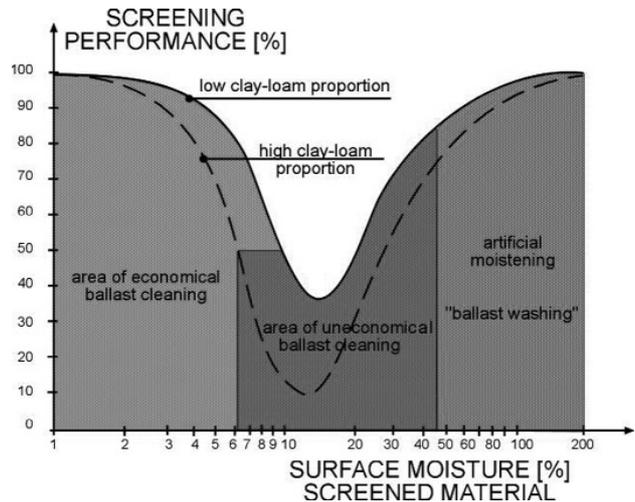


Fig. 12: Screening performance in relation to the moisture content of the ballast bed material (see [Ref.])

The cost/performance ratio speaks in favour of high-tech worksites whereby a high-quality result is achieved, making follow-up work to a large extent unnecessary. Many renowned railway administrations demand a worksite standard which ensures that, after ballast cleaning, the track can be reopened to traffic at 70 km/h.

### Logistics concerning the removal of spoil

When using the modern high-capacity ballast cleaning machines, considerable quantities of spoil are obtained that have to be replaced by new ballast. Depending upon the degree of fouling, per hour, as much as 350 m<sup>3</sup> of spoil can occur. Today, the spoil can only rarely be left at the side of the track. Especially in station areas, in narrow cuttings and in tunnels, the spoil has to be taken away at all events.

For the transportation of spoil, the Plasser & Theurer range of material conveyor and hopper (MFS) units offer an ideal complement to the machine systems performing ballast bed cleaning (and for the mechanical production of a track subgrade) (Fig. 13). All movements of material take place on the track under repair, without any disruption to the output of the ballast cleaning machine. Since the MFS units function like a conveyor belt line, loading is performed continuously, whereby the units at the end of the loading line are used for storage. The number of MFS units used has to be adapted to the prevailing worksite and operating conditions, whereby they can be configured in any length required.

When a number of MFS units are full, they are uncoupled from the machine and taken to a suitable location for unloading. Unloading is performed via slewing conveyor belts which, depending on the MFS design used, takes approx. 3-5 minutes. In the meantime, loading of the units that remain with the ballast cleaning machine continues. After the return of the empty MFS units, the material is passed on again and loaded into these empty units. Thus, the ballast cleaning machine can continue its work without any interruptions.

If a ballast cleaning machine is equipped with a ballast supply unit, new ballast material can be supplied also using MFS units, and these tasks performed continuously without disrupting the output of the ballast cleaning machine. Depending upon the worksite logistics, new ballast can also be placed directly by specially-equipped MFS units whereby, in contrast to other ballast transport wagons, it is possible to accurately dosage the amount of ballast needed.



Fig. 13: Ballast cleaning machine, together with material conveyor and hopper (MFS) unit for the supply of new ballast and the transport of spoil



*Fig. 14: The Plasser & Theurer RM 900 S ballast cleaning machine, which features a total mass of 345 t and a construction length of more than 100 m*

## CONCLUSIONS

As shown in this article, today, ballast cleaning machines form a challenge to the know-how and production capacity of the machine manufacturer. For instance, with respect to the engine, special training in hydraulics and motive power engineering is required. Further, the machines are controlled by newly-developed measuring systems and computer programs, in order to guarantee the required uniformity and accuracy of the work performed. Also, it is necessary to have specialist knowledge in the field of excavation and screening technology and, very often, the additional requirements of ballast treatment require extensive knowledge of processing technology.

Overall, for the production of such giant machines as ballast cleaning machines, with a total mass of more than 250 t, it is essential to have huge production areas and a great deal of experience in mechanical engineering.

The foundations have to be present in the minds of the design engineers to think in these dimensions, and also in that of the workshop staff, in order to be able to deal with such dimensions (Fig. 14).

Design engineers must also have visions for the future. How do they imagine the further developments of the machines? Without doubt, even more work functions will be incorporated into future heavy-duty machines and, in order to increase the outputs, the machine systems will have to be adapted, enlarged or multiplied, and the control technology further perfected. It would be interesting to see how, in several years from now, the ballast cleaning machines and large track maintenance systems will have developed!

## Reference

Lichtberger B.W.: 'Track Compendium', First Edition, 2005, ISBN 3-7771-0320-9.

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