INNOVATIONS IN MECHANISED TRACK MAINTENANCE

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SUMMARY

The first track maintenance machines were designed as prototypes in the 1930’s but it was only in the late 1950’s that such machines were actually produced in factory production runs. These tamping machines were about 9 metres long and weighed about 20 tonnes. Today, the largest tamping machines are 45 metres long and weigh up to 170 tonnes. Machines for other track maintenance operations are up to 270 metres long and weigh 1,000 tonnes. The output of tamping rose from 300 m/hr to 2.5 km/hr. This impressive development is based on the needs of the railways to optimise their operation.

The demands for work quality and the heavy track construction of today make the usage of high capacity machines, indispensable. The robust machine frames are a basis for high work accuracy and so is the work algorithm of fast machines for maintenance quality. For every maintenance task there are machines of different design and sizes available. For example, for tamping, the range is from two-axle machines with about 30 tonnes overall weight to high capacity bogie supported machines in three or four sleeper tamping mode. The art of the engineer is to select the right machine size for a given task. Often methods with initially low cost turn out to cause high follow up cost because the lack of precision and durability of the result.

Examples of Innovation in mechanised track maintenance are multipurpose machines for track and turnout tamping, ballast cleaning and track renewal which integrate a number of functions in one machine system; automatic sleeper distance scanning systems for tamping machine control and automatic adjustment of tamping tools; new methods of track stabilisation; ballast-, formation- and drainage rehabilitation technologies.

The use of high capacity machines to achieve high quality of work results in cost optimisation and is definitely not a luxury but a demand by today’s railway track infrastructure industry.

1. THE DEVELOPMENT

The first track maintenance machines were designed as prototypes in the 1930’s but it was only in the late 1950’s that such machines were factory produced. These tamping machines were about 9 metres long and weighed about 20 tonnes. Today, the largest tamping machines are 45 metres long and weigh 170 tonnes (Fig. 1). Machines for other track maintenance operations are up to 270 metres long and weigh 1,000 tonnes. Therefore, since the introduction of tamping

Figure 1: Machines in 1953 (left) and in 2011 (right)
machines in the 1950’s, the size and output of the machines have changed dramatically. The main driver of the development was on the one hand the demand to better utilise working windows between rail traffic, on the other hand higher working precision and longer lasting work output results were the goal. The development from tamping machines in the range of 10 tonnes to high capacity machines of hundreds of tonnes or greater reflects technical necessities to meet such demands.

1.1 Two Axle Tamping Machines

The first hydraulic operated track tamping machine was introduced in 1953. This marked a new approach where modern technologies were used to increase work quality, output and operating comfort. The two-axle machine had a 3.5 metre wheel-base and an overall length of about 9 metres. Its tamping units were located between the axles and the levelling and lifting of the track was undertaken manually.

In 1960 the next big step was to integrate more than one work operation into one machine. The combined lifting, levelling, and tamping machine marked a breakthrough in machine maintenance of tracks. The machines now were built on a cantilever design; where the tamping and lifting units were positioned ahead of the front axle. This design was retained until the end of the sixties. More and more work functions were incorporated into the machines, especially those of track lining. However, this resulted in problems when distributing the reaction forces of the track lifting and slewing process and thus to balance the machine due to its short length and relatively low weight. Therefore a new machine generation was introduced in 1967 – the SLC (Super Lining Control) series. These machines had a wheel-base of 7 metres, and a total weight of 32 tonnes. The middle part of the machine was elevated to provide improved operator visibility during travel (Fig. 2).

The next step was the introduction of the Universal Tamper in 1968 (Fig. 3). The arrangement of heavy tamping, lifting and lining units in front of the first axle caused very heavy impact to the front axle especially whilst the machine was in working mode. Therefore a change in design was introduced; with the Universal Tamper now having the lifting, slewing and tamping units positioned between the axles. The advantage for the user was:

- Distribution of axle loads was more even;
- Machine was more stable in working mode;
- Stability during working mode resulted in better track geometry;
- The machine could be attached to other vehicles at front and rear end.

Further advantages of the new design:
- Axle-base was increased to 8 metres;
- Total length was only 11.5 metres;
- Total weight was only 16 tonnes.

The above listed advantages of this new compact design were obvious; and it therefore became state of the art in the whole track machine industry. With this design it was possible to adapt the machine concept to the demands of the track, resulting in machines of optimal size and functions.

1.2 Four Axle Tamping Machines

When Universal Tamper were introduced on the world market in 1968, the track standard of main lines was 40 to 45 kg/m rails and wooden sleepers, train speeds were 60 to 100 km/h, with just a few exceptions. In the early 1970’s increase in traffic volume and traffic loads caused the demand for heavier track and better use of track possessions. The answer in machine design was the four-axle tamping machine (Fig. 4).

The larger axle spacing increased the lifting capacity. The main frame of the machine had standard railway vehicle characteristics, so the machine could be transported within standard train consists. That enabled faster circulation or transfer within densely used railway networks. The undercarriage with two-axle bogies improved the ride quality, so generally higher speeds could be achieved; the benefit
was faster travel to and from the worksite and therefore optimal use of the track possessions. In 1980 the next generation of such machines already weighed about 47 tonnes and had a bogie pivot spacing of 11 metres. Again the reason to change to a larger design was the continuously growing traffic and large scale use of heavier track design as UIC 60 rails and concrete sleepers.

1.3 Multi Sleeper and Continuous Action Tamping

The first leap in increasing tamping speed was in 1965 when the Duomatic Tamper — the two sleeper tamping machine was introduced with a tamping capacity of 800 m/hr. The Duomatic principle was subsequently applied within the four axle machines. By refining the work process, work speed could be raised to 1,200 m/hr. Due to further traffic growth, track maintenance machines had to become even faster in output. Therefore in 1984, Continuous Action Tamping (CAT) machines were introduced. The average output of such machines was about 30% higher than that of cyclic action machines; but they were also larger. A four axle “09-32 C.A.T.” which tamped two sleepers at a time had a total weight of 68 tonnes and a bogie pivot spacing of 12 metres. In Australia the first successful operating continuous action tamping machine was the one sleeper version, a “09-16 C.A.T.” (Fig. 5).

In 1996, a further 40% increase in output was achieved due to the introduction of three-sleeper tamping. Australia was amongst the first countries where this new technology was applied. 2005 brought the introduction of the four sleeper tamping machine, which at the time was the fastest and largest machine of this type, with a working speed of 2.5 km/h, a mass of more than 170 tonnes and a total length of nearly 45 metres (Fig. 1 - right).

2. TODAY’S DEMANDS ON TAMPING MACHINES AND TRACK GEOMETRY CORRECTION

2.1 Machine Design

In the sixties the typical mainline track had rails of 40-50 kg/m and wooden sleepers; whereas today the rail size is 60 to 70 kg/m and the pre-stressed concrete sleepers weigh up to 400 kg. The weight of a 10 metre track panel rose from about 2.5 tonnes to between 6 to 8 tonnes. At the same time annual traffic increased from a few million tonnes pa to more than 100 million tonnes pa on heavy haul lines. Also line speeds have increased from a typical 120 km/h to 160 km/h on standard lines and more than 300 km/h on high speed lines. The machine design of today is the answer to this growth.

2.1.1 Frame Design

The reaction forces of tamping and lifting cause deformation of the main frame of the machine during every tamping cycle. To demonstrate the difference between light and heavy frame design, Plasser’s test department measured such frame deformation on two-axle machines of lightweight design and on four-axle machines of the 08 U series (Fig. 6).

The difference in frame deformation was found to be significant (Fig. 7). Under heavy lifting conditions the frame of the lightweight machine would therefore be expected to wear out quickly by fatigue. The higher deformation of the frame during lifting also has a negative influence on the accuracy of the work output.
Therefore for heavy track work applications, a heavy frame design was therefore recommended as being required. Such heavy frames are now standard on Plasser machines.

2.1.2 Axle Spacing

The lifting action which takes place between the front and the rear axle causes rail deformation. With a larger axle spacing the bending moment "line" of the lifted track becomes smoother and less stress is produced in the rails (Fig 8).

![Figure 8: Difference in bending line of track with short and long axle spacing](image)

Therefore, lifting of heavy tracks demands that a long axle spacing be built into the machine. Decisive for a positive effect is the distance between the lifting unit and the front axle as rail bending takes mainly place between those two points. Shifting the rear axle to the back (shown in light grey at the left side in Fig. 8) does not contribute to stress relief, therefore the rear axle should be placed as near as possible to the tamping unit.

The stress on the rails during lifting has to be kept within certain limits. On rails with a grade of 90 kN/cm², (refer to the European Standard ENV 14033–1 – “Railway Applications / Track – Demands on Commissioning of Construction and Maintenance Machines”) requires a maximum stress of 45 kN/cm² during the levelling and lifting process. If the rails are overstressed, the result will be lasting rail deformations or even broken rails.

Figure 9 shows the rail stress over the axle spacing at certain lifts. The machines are actually capable to carry out track lifts of up to 15 cm in physical terms, however when carrying out production tamping on high quality tracks their lifting operations should be restricted to 10 cm per pass (as compaction of the ballast under the sleepers is insufficient if the lift is too high). With a lift being limited to 10cm, and with 10 to 12 metre axle spacing, the rail tension can be kept well within the EN Standard. The inner axle spacing of four-axle continuous action machines is 12 metres, and therefore such high lifts can be carried out without overstressing the rail (Fig. 10).

![Figure 10: High track lifting capacity](image)

2.1.3 Working Speed versus Working Accuracy

The development of two, three and four sleeper tamping machines in continuous action mode has increased tamping speeds to more than 2.5 km/h. But what has been the effect on the accuracy of their work output? Even since the development of Duomatic machines it was noticed that the accuracy of the track geometry behind the machine was generally higher than with single sleeper tampers. The introduction of three-sleeper tamping machines raised the track quality even higher. In 2001, three years after the introduction of three sleeper tamping machines as standard practice on all main
lines in Austria, Dr. Gerard Presle, Head of Track Technology of Austrian Railways quoted that “the average track quality had been increased by 20% compared to the years before, when two sleeper tamping machines were standard”. Austrian Railways use a “dynamic” Track Quality Index based on track geometry measurements which are integrated over the line speed. A comprehensive track data base, which was implemented in the mid 1990’s, enables the analysis of such trends in the Track Quality Index. The reason for the increase in quality is that multi-sleeper tampers have a smoother lifting action because a larger panel is lifted at every cycle and the axle of the tamping satellite is resting on the track which is already lifted and tamped, so it cannot be moved again by the following lifting process (Fig 11).

Another important factor for the accuracy of the work of continuous-action tamping machines is the separate under-frame for the work units. During the lifting, lining and tamping process all work units involved must rest at the work area. The tamping, lifting and lining units are therefore mounted on a “satellite” which moves in a cyclic action while the machine itself moves forward continuously (Fig. 12).

Earlier trials with designs where only the tamping unit was cyclic, and the lifting-lining unit was moving continuously, revealed that no satisfactory track geometry could be achieved; as the continual change of position of the lifting unit did not allow the track to be fixed in its final correct position by tamping.

The high initial quality which can be achieved with continuous multiple sleeper tampers results in reduced track maintenance effort having to be imparted into the track structure, due to the use of a continuous-action tamping machine.

2.2 Precision of Track Geometry

The relationship between track quality and dynamic axle forces is evident. Errors in track geometry cause dynamic forces when trains pass over them and these forces in return amplify geometric irregularities.

At the Heavy Haul Conference in Beijing, 1993, Rießberger showed the relation between track quality and dynamic axle forces, based on the track calculation model of German Railways as developed by Eisenmann and applied by DB (German Rail). At the next conference in Capetown, 1997, R Chopra and A Krishan of Indian Railways presented a field study based on this. The conclusion of both papers was to keep track forces low by high quality track standard. Low track forces also mean to have low dynamic reaction forces on the wheels and thereby on the rolling stock.

With the increase in axle loads more attention is being made by the track maintainer to the elimination of track geometrical errors of longer wavelengths. Also the absolute position of the track becomes more important within curves. If the track moves from its original position over the time, the rail stresses change. This is particularly important on curves where any increase in compression stress within the rails increases the risk of track buckling. Wherever passenger and heavy haul freight traffic is envisaged, precise track geometry is an absolute must for the track maintainer.

2.2.1 Smoothing Method

The compensation (smoothing) method is still the most applied geometry correction method used in tamping machines. For leveling, the front reference point of the leveling system runs on the uncorrected track, with the rear reference point running on the corrected track. The leveling sensor in-between (near to the lifting unit of the machine) controls the lifting.
process. Errors in the longitudinal level are reduced by a factor, depending on configuration of the measuring system and the wavelength of the error. Mathematically this error reduction process is described as the "transfer function" of the measuring system. After repeated application of smoothing leveling and lining, the track will develop remaining errors of longer wavelengths and loose its design geometry, a situation which is unsatisfactory for high capacity traffic.

2.2.2 Precision Methods
To correct long wave errors or bring the track back to its design geometry, additional external inputs to the on-board measuring systems are necessary.

The development of on-board track geometry computers like the "Win-ALC" (Fig 13) was first aimed to enable automatic work-mode in all forms of curves, as well as also allowing the input of any design data required.

The computer system also includes the “factor algorithm” for compensation of long wave errors. The first part of the process is a recording run which is performed by the machine. The software then recalculates the recorded levelling and lining values by considering the transfer function of the measuring system. By this process, also long wave length errors (of up to 60 metres) can be eliminated.

On European high speed lines the track geometry always refers to reference points alongside the track. These fixed points are mostly mounted on the overhead electrification masts. A track survey car like the "EM-SAT" provides fully mechanised measurement of the actual track geometry using laser reference chords. The recorded data and the calculated correction values are displayed on a computer screen in a similar manner as on the on-board screen of the tamping machine and these can be reprocessed by the tamping machine, as is necessary. Electronic transmission of data to a tamping machine equipped with an automatic guidance computer guarantees the highest level of precision and at the same time prevents any transmission faults which can occur during manual measuring.

2.3 Selecting the Suitable Correction Method
The pattern of track geometry errors determines the mode of correction (Table 1):

<table>
<thead>
<tr>
<th>Appearance of Errors and Correction Methods</th>
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<tbody>
<tr>
<td>Pattern</td>
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<tr>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Frequency of appearance</td>
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<tr>
<td>Single spot error</td>
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<tr>
<td>Repeated appearance</td>
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<tr>
<td>Wavelength of errors</td>
</tr>
<tr>
<td>1 – 3m</td>
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<tr>
<td>3 – 20m</td>
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<td>20 – 100m</td>
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Table 1: Failure correction methods

2.4 Dynamic Track Stabilisation
In many countries dynamic track stabilisation has become a proven and essential part of the track maintenance strategy. The reason for its introduction on many railways was to recover the horizontal stability of the track structure immediately after track maintenance operations, such as tamping. Besides a rise in safety, there was above all a saving in the cost associated with speed restrictions that were previously imposed following ballast tamping operations.

Today, more attention is being paid to the positive effect on the vertical stability of the track's geometry. After ballast tamping, the action of operational trains over the new tamped ballast bed, cause initial and irregular settlement of the track, and which "sows the seed" for the development and propagation of
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further track faults. The DGS Dynamic Track Stabiliser, on the other hand, effects a uniform initial settlement which is equivalent to the effect of running approximately 700,000 to 800,000 gross tonnes of operational rail traffic on the newly tamped ballast bed. The range for further settlements is therefore restricted and the corrected track geometry is preserved for longer. The result of this pre-induced track settlement is an extension of the maintenance cycles by approximately 30% (refer to Dr. Lichtberger’s book, “Track Compendium”).

On new track construction it is important to stabilise the ballast layer by layer, and each tamping run should be followed by a stabiliser run. This is an inevitable precondition for the construction of a truly stable track from the beginning. The concept of the Dynamic Tamping Express has the advantage, that stabilising is always available in the same consist as the tamping machine.

3. INNOVATIVE WORK METHODS FOR TRACK MAINTENANCE

Low quality track causes high dynamic forces, and high dynamic forces cause overstressing of the track infrastructure and the rolling stock travelling on the track. This results in greater maintenance costs and shorter service life of the rolling stock.

The European track maintainer therefore demands a long lasting result following any track surfacing operation. When track has developed a quality level as low as the intervention level, scheduled maintenance by a machine group consisting of levelling, lining, tamping, ballast profiling and stabilising machines (MDZ) is generally carried out.

As the maintenance operation should be completed before the first operational train passes over the track, a complete machine group is used, where the machines are matched in design, travelling speed and working speed. Special attention is also needed to ensure that the ballast regulating machine has enough capacity within the machine set (Fig. 14) to match the performance and output of the other machines in the workgroup.

In between scheduled maintenance cycles, even well maintained tracks can develop single spots having track geometrical faults over a limited length (typically over 10 to 20 sleepers). Although the general condition of the track is still within the permissible limits, the spot faults may cause ‘Speed Restrictions’ or ‘Slow Orders’ to be imposed because they are exceeding the operational safety limits of the line segment. The usual practice to treat these spots by intervention with very basic machines or by power tools is counter-productive, as they often re-occur very soon after initial intervention works. The solution is to use a multi-purpose tamping machine equipped with universal track and switch tamping capability, a ballast profiling system and a special measuring and compensation program for spot errors.

For budget reasons, often “patch work surfacing” is carried out where only short sections of 100 to 200 metres in length are treated with the sections in between remaining un-tamped. From a short term financial point of view such a strategy is very tempting, but the result is a non-homogeneous track condition which leads to the necessity of more frequent surfacing. In addition the lower overall quality shortens the service life of the track.
3.1 High Performance Machines

Tamping machines are designed in different sizes, from simple two axle machines (Fig. 5) to heavy multi-body machines with bogie suspension (Fig. 14). Tracks of high capacity railways (freight and passenger) are generally of heavy design and have large size rail profiles. To be able to lift those tracks without causing damage on the track or the machine, a large axle or bogie pivot distance and sturdy machine frames are desirable. If there are long distances between worksites, high travelling speeds are also required. This is also a reason for bogie suspension.

The output categories of tamping machines vary, from single sleeper insertion in cyclic mode to four sleeper insertion in continuous action mode. When selecting the machine type, the advantage of better work results of multi-sleeper tampers of heavy design should be considered.

3.1.1 High Speed Tamping at Irregular Sleeper Distances

Tracks with irregular sleeper spacing (Fig. 15) are a special challenge for high speed tamping. For long time it was believed, that only basic single sleeper tampers are suitable for such tracks. The introduction of continuous action tamping enabled new possibilities. First it was the "09-16 C.A.T." (Fig: 5) which enabled higher outputs to be achieved on such tracks.

Because of the increasing scarcity of long track occupation work blocks, the interest in multi-sleeper tamping is continuing to rise. Together with three-sleeper tamping, tamping units were developed which can, at any time, switch over to single sleeper tamping mode, whenever the spacing becomes too irregular. The four sleeper tamper has even two such options: switch over to one or two sleeper tamping modes, as and when it becomes necessary (Fig. 16).

A newly developed sleeper scanner (Fig. 17) enables new possibilities which are used within the “09-3X Wood” machine.

Two baseplate / fastening scanners (left and right) are mounted at the front of the machine. The position of the sleepers, regarding spacing and angularity, are stored in the machine’s processor and when the tamping unit reaches...
the scanned point, they are adjusted accordingly. The three sleeper tamping unit of the continuous action tamper automatically adjusts to the varying sleeper spacings that are recorded by the scanners. The automatic control either adjusts the tamping tool distance or switches the machine to single sleeper tamping mode, if the spacing is too tight or irregular for two or three sleeper tamping (Fig. 18).

The latest development is the “09-3X Concrete / Wood” machine for the USA. There, the average sleeper spacing of tracks with concrete sleepers is 600 mm and, on wooden sleepers it is 500 mm. The tamping units of the “09-3X C/W” machine are split in two parts and can be additionally adjusted to such a wide variation in sleeper spacing (Fig. 19). Still, the automatic sleeper scanner allows the same adjustments as it does on the “09-3X Wood” machine.

3.1.2 High Speed Tamping in Turnouts
Parallel to high speed tamping machines for tangent track, machines for turnout tamping had been developed which included the same design principles as high performance tamping machines. The complexity of turnouts demand machines which enable the tamping and maintenance of Switches and Crossings (S&C’s) without causing any damage. For the new generation of high capacity turnouts now in service the application of these machines is the only way to preserve the high quality of these costly assets.

Heavier designs of switches and crossings due to the use of concrete bearers and heavy rail profiles demand additional measures for their treatment. When lifting such turnouts in the area of the long bearers with the standard two rail lifting unit, the reaction forces on their fastenings are already exceeding their yield strength. This was first detected on German Railways DB and therefore an additional lifting arm for switch and crossing tamping machines had been developed. By utilising this lifting arm, the turnout rail is simultaneously lifted with the rails of the main track and any undue stress impacting upon the fastenings and sleepers is thus avoided. This additional feature, being the “3 S” type lifting, is now standard for S&C Tamping Machines. On most European railways three rail lifting on turnouts with concrete bearers has become mandatory.

In addition to 3-rail lifting, the 4-rail tamping brought about a further improvement in the quality of S&C maintenance. The three rail lifting and four rail tamping system is applied on cyclic Tamping Machines as well as on one- and two-sleeper Continuous Action Universal Tamping Machines.

In turnouts the establishment of an “exact target position” is as important as in main line tracks. Fixed point systems are therefore also applied. In addition it is very helpful to use machines which are equipped with a laser lining and levelling system.

On main lines there is the same time constraint for turnout maintenance, as for track maintenance. Continuous action tamping and combination of dynamic stabilisation and ballast regulation in one machine is therefore the solution which enables maximum use of track occupation work blocks and necessitates that high precision work be performed (Fig. 20).
3.2 Conclusions for Tamping

A great number of publications have shown the amplifying effect that poor track quality has on dynamic wheel/rail interaction. Therefore, a high track quality does not only impact upon ride comfort, but also affects the level of stress exerted on both the rolling stock and into the track structure. High-quality track maintenance methodologies therefore enable the life-cycle costs of both the track structure and rolling stock to be kept to a minimum.

Today, there are machines of different sizes available for track maintenance. The range is from two-axle machines with about 30 tonnes overall weight to high capacity bogie supported machines in three or four sleeper tamping mode. Selecting high capacity tamping machines for lines with high axle loads is not a luxury but a requirement to achieve high quality of work output at a minimum cost. On lines with passenger traffic, the application of precision methods for track geometry correction has continued to gain importance in the European rail industry.

4. INTERACTION OF BALLAST AND TRACK QUALITY

The quality of track geometry is not only defined by the prevailing Track Quality Index, but even more important by the ability to produce a high initial quality ballast bed having a low rate of degradation.

One of the most important factors for both is the state of the ballast. Stones of lesser quality and too many fines in the ballast rapidly cause deterioration in the Track Quality Index. For ballast that has been in service and in track over long periods, fines and blocked drainage are generally the main problems.

If ballast and drainage are not well maintained, the effective lifetime of the track material is also dramatically reduced. Concrete sleepers are especially prone to serious damage by fouled ballast (Fig. 21). Fouled ballast cannot fulfil its load distribution function, therefore very often, long time neglect of ballast maintenance interventions leads to failing of the formation and very high subsequent rectification costs.

4.1 Ballast Cleaning

When track geometry maintenance becomes frequently necessary due to fouled ballast, maintenance of the ballast, by ballast cleaning, is generally the most economical solution. Prior to the use of undercutter cleaners, track ballast sleds were used which just ploughed the ballast to the side. The disadvantage of this method is that sleepers are damaged and ballast is ploughed into the shoulder and affects the adjacent drainage. Ballast cleaning is normally performed in conjunction with partial re-sleepering or
complete renewal of the track. In the case of complete renewal of the track, mechanised ballast cleaning should be carried out in any case, even if the degree of ballast fouling is less than the allowable value, which is not more than 30 to 40 % of fines smaller than the 22mm sieve within the ballast (refer UIC recommendation: ERRI D 187 rp3: "Unified Assessment criteria for Ballast Quality and Methods for Assessing the Ballast in Track").

The quality of the initial ballast bed produced by the ballast cleaning machine is essential for cost-efficient maintenance and long service life of the permanent way. Generally, ballast cleaning should be performed before the track renewal process to ensure that the new track components are not subjected to any undue stresses.

For high density lines, high output ballast cleaning machine systems are generally used (Fig. 22). A dynamic track stabiliser is integrated into such machines, where it performs a first consolidation of the ballast bed. Safe train passage is then possible immediately behind the ballast cleaning machine and the number of subsequent tamping cycles can therefore be reduced. To ensure that the increase in output generated does not adversely impact on the quality of the cleaning process, ballast cleaning machines with double or triple screening units are used to increase their output.

4.2 Combined Track Relaying and Ballast Cleaning

A machine that revolutionises track renewal is the continuous action ballast bed cleaning and track renewal train (Fig 23). This machine combines the two working operations of ballast bed cleaning and track renewal in one single machine. This makes it possible to perform the renewal of sections of track in only one track possession, with all of the associated technological, logistical and above all, economic advantages.

The challenge in the machine’s development was to integrate the operation of ballast bed
cleaning with its necessary movements of track material components into the operation of track renewal to ensure that the technologically complete sequence of operations were all achieved. The effective construction gap between the removal of old sleepers and the installation of the new sleepers is only around 11 metres long. The materials are all transported within the machine along distribution routes that are as short and direct as possible.

The supply of new sleepers to the track laying unit called for innovative ideas, as its transportation route was forced to cross the ballast conveyor belts, where the new sleepers are effectively turned 90 degrees in pairs, and are channelled lengthwise, past the ballast conveyor belts, then before their installation, when they are turned round again. It is also possible with this system to work with most different types of sleepers.

With this “RU 800 S" machine consist, the laying of the new sleepers and the new rails is performed after the excavation of the ballast bed and the insertion of the cleaned ballast in accordance with track infrastructure Standards, which requires that a clean ballast bed is essential beneath the new concrete sleepers.

The ballast excavating chain, which is positioned between sleeper pick-up and the laying mechanism, is designed for an excavating width which guarantees that the excavation occurs over the entire length of the sleeper, subsequently ensuring that a precise bed can be produced for the new sleepers. On the other hand, it allows the absolutely simple excavation of all of the ballast bed material in restricted situations, such as in the vicinity of station platforms.

Furthermore, the ballast is consolidated before the new sleepers are laid. This means that the previous practice of a first tamping pass, following the machine’s track laying operation can be eliminated.

Between April 2006 and December 2010 more than 400km of track were renewed and cleaned in Austria and Germany using RU 800 S relaying train consists.

Formation Rehabilitation

It is not only both the increase in axle loads and train speeds, but also the construction of tracks on formations with low bearing capacity and neglected drainage, which leads to formation failure. Defects in the bearing capacity of the formation are the catalyst for formation failures by which mud pockets are created, which over-time and in conjunction with the presence of water, lead to pumping of slurry through the ballast bed. The whole track then loses its horizontal and vertical stability. Defects in the bearing capacity are not only caused by both increases in axle loads and train speeds on existing lines, but also are a direct result of deferred ballast cleaning and blocked track drainage. Such pumping can usually be prevented by placing a blanket material between the ballast bed and the formation.

A typical attrition and mud pumping spot is shown in Figure 24.

![Figure 24: Test pits showing formation overloading and penetration of soil into the ballast](image)

The first indication of formation failure is the necessity for frequent track tamping and the very quick return and evidence of ballast fouling after track undercutting and ballast cleaning. Track geometry recording cars with the “ADA 2” Analyzing System, manufactured by Plasser & Theurer, can measure and record quality indices for the formation, known as the Formation Index. The Formation Index is calculated on an empirical basis and uses the twist based on a 16 metre chord length.

The classic method of formation rehabilitation is to dismantle the track and use road construction equipment to excavate ballast and formation material, bring in the new material, distribute and compact it and then lay the track again. This “open construction” method, generally known as “track reconditioning” provides good access to the formation but has also some major disadvantages:

The track is closed to traffic for the whole rehabilitation period, this can last several
weeks and large amounts of material have to be transported in and out by trucks. Very often the formation is too weak to carry the trucks and the construction equipment, and water traps are consequently created, which will very soon cause new formation problems.

The alternative is to use on-track equipment which can carry out formation rehabilitation without the necessity to dismantle the track. In 1984 the first track-bound formation rehabilitation machine, the PM 200 was developed by Plasser & Theurer and put into operation by a German railway contractor. This machine excavates the ballast and formation under the existing track, transfers the fouled material onto special rail wagons which are marshalled in front of the machine, inserts the gravel-sand mixture behind the excavating chain, grades and compacts this material, inserts the first layer of new ballast and tamp the track using an integrated continuous action tamping unit. The result of this innovative technology is that rail traffic can commence immediately on the newly rehabilitated track at speeds of 70 km/h.

After the introduction of the first system, as described above, the next step was to integrate material recycling, where the fouled ballast is either cleaned or crushed down to the aggregate size of the blanket material. Numerous systems of varying design are in operation on most Middle European railway networks. Lately, China has invested in this technology by already introducing fifteen (15) such Formation Rehabilitation train consists into their operations.

4.2.1 New Technology with Three Excavating Chains

The latest unit is known as the “PM 1000 URM” which includes a further enlarged proportion of recycling (Fig. 25). With a total length of 270 metres, this machine is equipped with three excavating chains and the plant mechanisms required for ballast recycling. The enlarged recycling process offers a higher potential for savings in respect of materials required and transportation logistics. The “PM 1000 URM” removes the ballast bed material using three excavating chains. The first chain removes the upper layer of ballast, all of which is passed on to the recycling process. This consists of pre-cleaning the ballast in a ‘roller sizer’ and a ‘finger screen’, sharpening the ballast in an impact mill and screening out the fine particles, using a vibration screen. To finish off the process the ballast is cleaned in a washing-screening unit and the water used for this process is retained and treated by the plant components located on the machine.
The second chain removes the material in the mixed zone. The next stage is a ‘roller sizer’ which separates the remaining ballast from the fine particles (passing 55 mm) and the ballast then continues through the recycling process. The fine particles obtained are collected and used for production of the intermediate layer, which is already a part of the new layer-by-layer structure. This layer is placed on a geosynthetic fabric which is laid directly behind the third excavating chain, and which removes the remaining ballast bed to the desired formation level. The Formation Protective Layer (FPL) is placed on top of the intermediate layer, if necessary with another geosynthetic fabric provided as an intermediate layer (Figs. 26 and 27). To complete the rehabilitation process the track is filled with recycled ballast, then lifted, lined, levelled and tamped.

5. CONCLUSION

A continuous innovation process is the basis of track maintenance machines that are available today. The focus of development is always on technical and economical demands. Large machine systems as they exist today are the key for a sustainable track system. The achievement of low track geometry deterioration rates becomes the sweetener as the track infrastructure owner / maintainers' compensation for their investment in such innovative and high productivity track maintenance machines.

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