High-capacity, precision and reliability in track maintenance

Faults in the track geometry, running gears in poor condition and lack of harmony between wheel and rail are the cause of large dynamic forces – not only in the track but also in the rolling stock. Higher operation speeds also demand a perfect track geometry, especially when using tilting trains. International progress reports and studies prove that timely track maintenance and the application of high-capacity, precision machines is the most cost-favourable maintenance strategy for the railways. The latest developments in track maintenance technology were shown at the International Exhibition of Track Technology iaf 2006 in Münster, Germany.

1 Interaction between track quality and track wear

The function of the track is to allow trains to run with the lowest possible and most uniform level of force. Whereas the track forces acting statically are mainly dependent on the selected axle loads, defects in the quality of track and/or running gears and unfavourable curves will cause dynamic forces that often amount to many times the static axle load.

Track quality is not simply a geometric property. The rigidity and bearing strength of the individual components also play an important role. Maintenance operations must therefore relate to all parts of the superstructure and the substructure [1]. (Fig. 1)

1.1 Interaction between track quality and rail wear

The deformations and damage resulting from wheel/rail problems are based on the dynamic forces which are caused by the wheelsets. Generally, the vertical and horizontal forces and creeping forces have to be considered. According to Knothe [2] the vertical forces and the creeping forces as well as the elastic properties of the material are the main parameters for the calculation of contact forces, which can lead to an over-stressing of the contact forces in wheel and rail. The vertical forces depend of course on the static axle load, the travelling speed and the vehicle dynamics, but they are also influenced to a considerable extent by the track quality.

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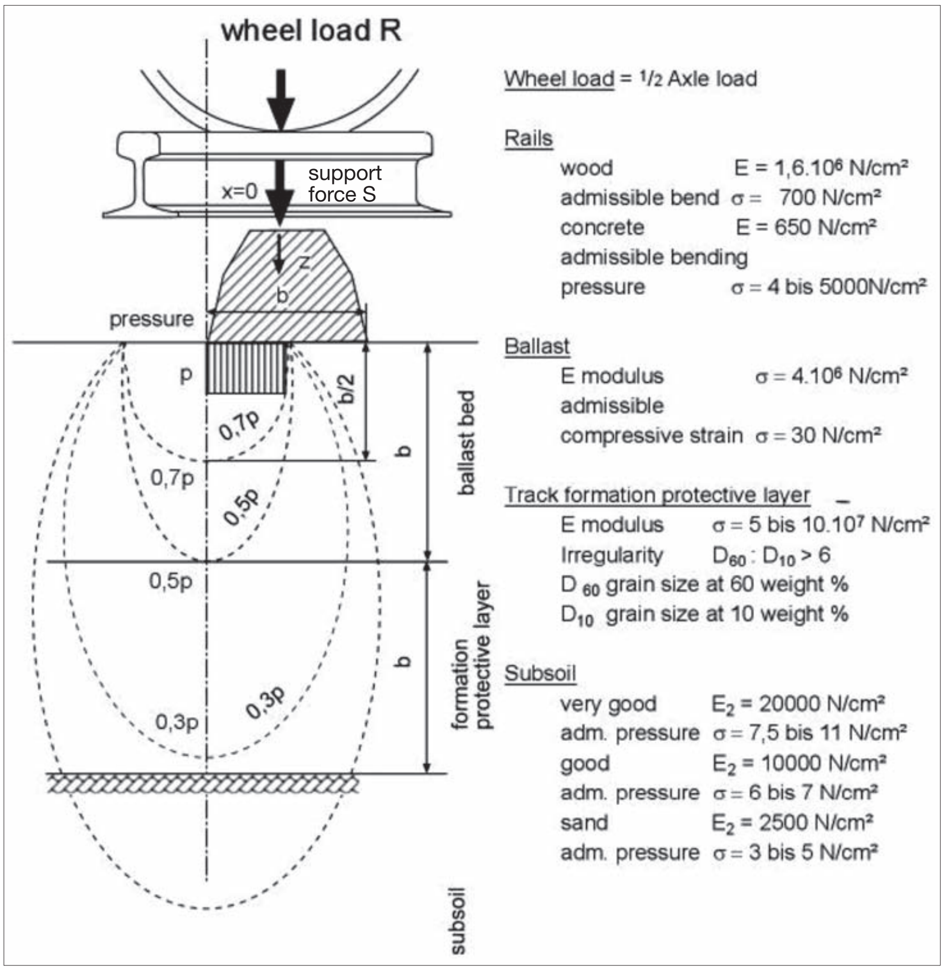

Fig. 1: Distribution of force from the wheel to the subsoil

1.2 Interaction between track quality and dynamic forces

For calculation of the wear on the permanent way and for the design of the track components, it has long been standard practice to apply the Zimmermann model [3] which is based on static loading of an elastic bearer. The dynamic model developed by Eisenmann [4] for dimensioning the permanent way takes into account that the vertical forces (axle forces) are dependent upon the track quality. The maximum forces occurring are determined on the basis of static evaluation taking into consideration speed and track geometry (Fig. 2).

The maximum force Qmax is calculated from the average force (e.g. of the quasi-static axle load) Qmean multiplied by an amplification factor which is calculated from the factors speed and track quality. The original formula was adapted in the course of the years. As can be seen in Figure 2, the influence of speed up to 60 km/h is negligible, but poor track quality influences the forces in all cases. For better clarity the terms “excellent”, “average” and “poor” have been replaced by the terms “main line”, “secondary line” and “other lines”.

Where there is excellent track quality, therefore, the average axle load can be raised without increasing the maximum forces. From this, the reverse conclusion can be drawn that better track quality reduces the dynamic loads and reaction forces, and consequently the wear.

When designing the high-speed lines for the TGV in France, the correlation between track forces and track quality was also taken into consideration. J. Alias [5] developed a formula containing those factors which cause a rise in the dynamic forces.

The standard deviation of the additional dynamic forces $\sigma\Delta q$ (t) is calculated as follows:

$$\sigma\Delta q = kV\sqrt{2mh}$$

k = coefficient for geometric quality of the track
V = travelling speed (km/h)
m = unsprung masses (t)
h = track stiffness (t/mm)

This formula also shows the proportional share of the track quality in wheel/rail contact forces. It should be noted that the influence of the unsprung masses is also included.

In summary it can be clearly seen: by maintaining a good track geometry the rail/wheel forces can be kept low and this will reduce the wear.

1.3 Interaction between sleeper seats and dynamic forces

A further factor which influences the development of dynamic forces is the quality of the sleeper bed. Hollow cavities under sleepers or soft spots in the ballast bed will cause higher dynamic forces, as illustrated by G. Cope in “British Railway Track” [6]. Under the conditions prevailing on British railways, it is foreseen in the event of “soft spots” to add an increment to the continual wheel/rail contact forces which may be as much as 1.75. Consequently, the maximum force can reach 2.75 times the standard forces (Fig. 3).

The shape of the curve reflects the fact that above a certain ratio of (velocity/ length of irregularity (V/L) the forces lessen and the wheels start to “fly” over the depression. On the other hand, it can be concluded that, contrary to general opinion, considerable dynamic effects can occur on slow-running goods trains.

1.4 Interaction between track quality and lateral forces

The lateral movements of the wheelsets are a further aspect of the combined action of wheel and rail. Here too, faults in the alignment can cause considerable reaction forces. The Association of American Railways AAR Report R-797 [7] shows for example the difference between the calculated and the actual lateral forces in the turnout area. The higher forces measured result from a single alignment fault at the start of the turnout. The train speed was 80 km/h and the lateral force increased from 50 kN to 150 kN. In test sections without such faults, a good correlation between calculation model and measurement was determined (Fig. 4).

Measurements taken by Austrian Federal Railways show the same tendencies [8].

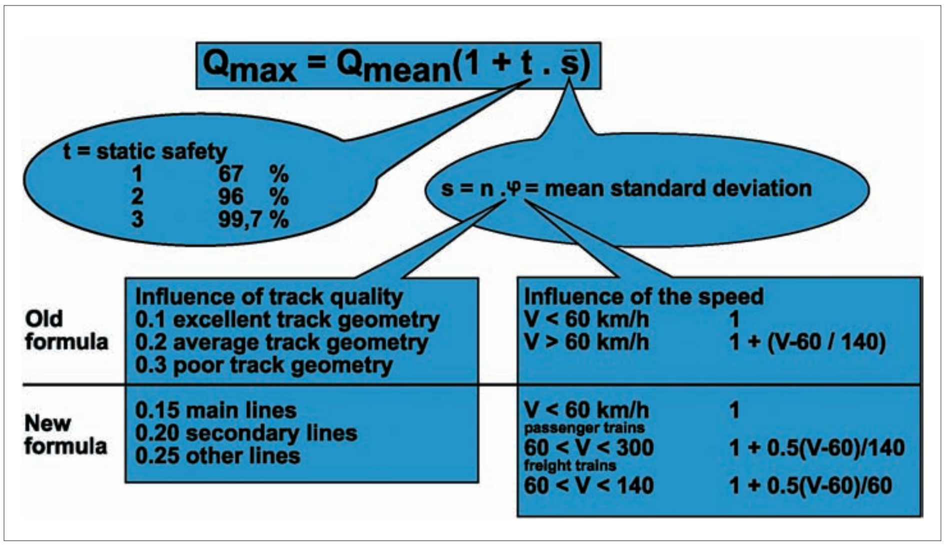

Fig. 2: Formula to calculate the maximum dynamic vertical forces Q_{max} between wheel and rail

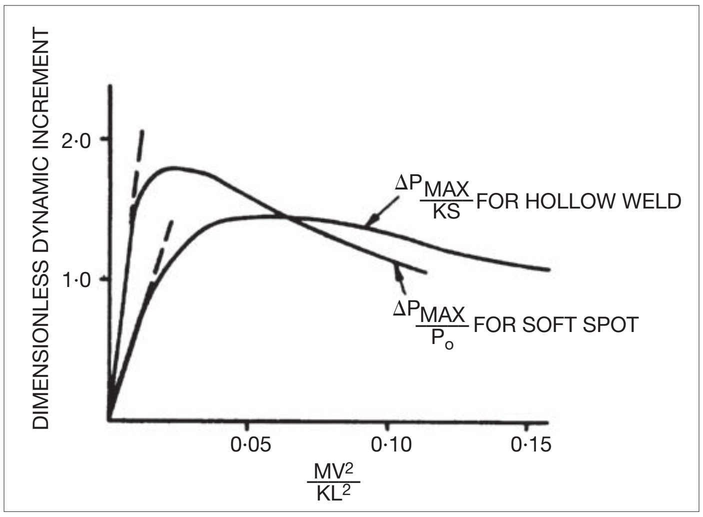

Fig. 3: Dimensionless dynamic increment for a hollow weld and a soft spot

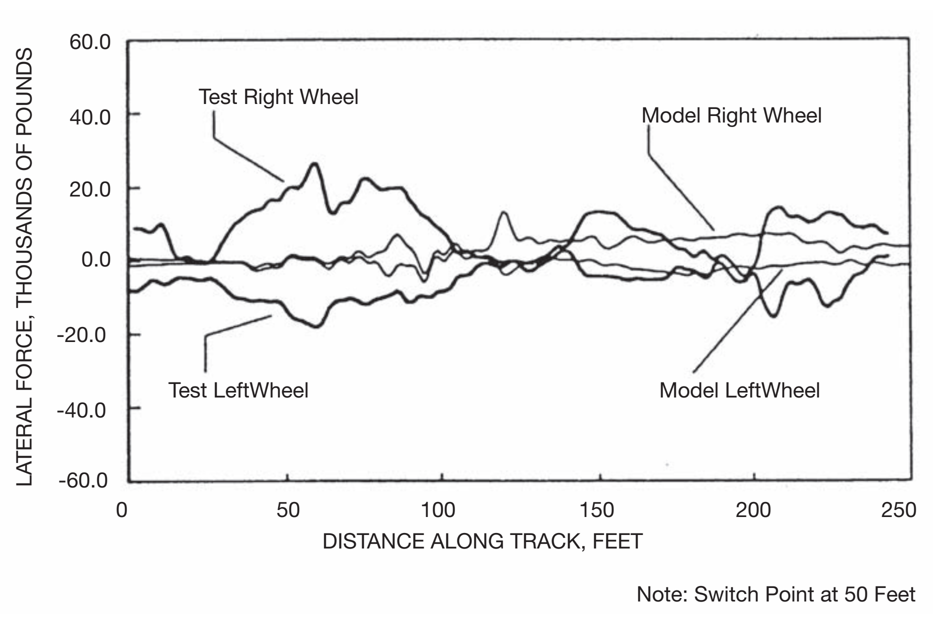

Fig. 4: Excerpt from the AAR Report 797

2 Track quality and stress on running gears

Low quality track causes high dynamic forces, high dynamic forces cause over-stressing of the rolling stock. The "normal" effects of poor track geometry are greater maintenance expense and shorter service life of the rolling stock.

Under certain circumstances a poor track geometry can also lead to a total failure. Mr. Hallstein Gasmyr of Norwegian National Railways and Mr. Jon Norman Ly, Chief Engineer in the field of traffic safety and rolling stock, proved in their study of a series of axle breaks on tilting trains in Norway that, despite UIC conform axle calculation, overstressing occurred in tight curves because the dynamic forces, caused by single faults that actually exist, are not included in the calculation [9].

3 Strategies to lower costs in the long-term

3.1 ÖBB Project "Strategy Permanent Way"

The "strategy permanent way"-project of Austrian Federal Railways developed from a cooperation with the Institute for Railway Engineering and Transport Economy of the Technical University of Graz and was presented at a UIC Conference held in Budapest in October 2002 [10]. The objective is to achieve an expert system which allows largely automated, technically and economically optimised and at the same time status-dependent track maintenance. This target cannot be achieved in one single step as it requires efforts to be made in all areas of track maintenance, from inspection, analysis and linking of track data to the actual maintenance programmes. The project is being developed continually, as described in an ÖVG publication issued in September 2004 [11].

An economic analysis of a project is based on the monetary appraisal of all effects, also including action taken later. A profitability calculation must therefore include at least the entire service life of a track, that is the period from one track renewal to the next track renewal. The long periods of use require the application of dynamic profitability calculations.

In this case, the elaboration of technical-economical maintenance strategies is based on an optimisation of the entire life-cycle costs. For this purpose the individual components of the track are investigated separately in sub-projects.

The sub-projects already completed are:

- ▷ Strategy permanent way tracks
- ▷ Strategy permanent way turnouts
- ▷ Strategy railway crossings
- ▷ Strategy bridges
- ▷ Strategy tractive units

Each of the above mentioned sub-projects consists of the following stages:

- ▷ basic investigations (description and analysis of the actual situation, developing strategies and assessing their economic efficiency),
- ▷ converting the results into new guidelines,
- ▷ passing on the results to all ÖBB organisational units working on the respective maintenance task and
- ▷ if necessary, carrying out trials on the track.

The results and recommendations are therefore covered both theoretically and in practical terms.

One of the first analyses showed the dominating position of depreciation for all types of traffic loads examined and indicated that the strategic approach for the permanent way must lie in an extension of the service life. Any shortening of the service life, despite the reduction in maintenance costs, can never be cost-efficient.

Further analysis of the cost structure allows the main cost drivers in the permanent way to be identified and these are briefly described in Table 1, listed according to their importance.

The table also shows the significance of operational hindrance costs for lines with average to heavy traffic. These costs are a decisive factor when deciding on the appropriate permanent way maintenance strategy.

Knowing what these cost-drivers are, enables strategies to be developed which have a positive effect on technical and economic aspects of permanent way and, on the other hand, they also reveal interactions that go beyond the field of maintenance, thus facilitating overall optimisation.

4 Machines to lower costs for track maintenance

From the afore-mentioned statements, the demands on the machine development can be seen which are reflected in the Plasser & Theurer production according to the maxim: "High capacity, precision, reliability".

In detail this means:

- ▷ The working and travelling speeds of the machines must be high enough so that operational hindrances – caused by the work needed – are kept to a minimum.
- ▷ The quality and precision of the work result must guarantee that large maintenance cycles can be achieved and a long service life of the track is possible.

- ▷ The machines must be in sturdy, heavy-duty design, assuring careful handling of the track material [12].
- ▷ The reliability of the machines must ensure operation without breakdowns [13].

Moreover, the strategy of maintenance and therefore machine development must regard the system as a whole and aim to develop suitable maintenance methods for all sectors of the permanent way (Figure 5) [14].

New developments, which are described in the following, fulfil these fundamental requirements.

4.1 Track maintenance

4.1.1 Producing the design geometry of the track

It is necessary to keep the actual track geometry close to the design geometry in order to keep a check on the rail tensions and to ensure smooth vehicle running with low dynamic forces. In Germany and Austria, therefore, after a phase of track geometry correction using the compensation method, track marking was re-introduced in the 1970's. Also in other countries, for example in Great Britain, France or Switzerland, track marking was re-introduced. Mechanised measurement of the deviations from the design position and the relevant fully automatic correction are therefore a hot topic.

Marking points (fixed points) are normally positioned on catenary supports. The distance of the track to the fixed point (height and alignment) is defined precisely at this point and between them the versines in relation to an imaginary reference chord from fixed point to fixed point are known.

The first developments which made it possible to work in curves with levelling, lining and tamping machines were the on-board systems DLT and DRIVER [15]. These units combined of laser direction-finding system and on-board computer had some disadvantages: they slow down the working speed of the machines and above all it is difficult to react to unexpected deviations to geometry in a manner correct for the engineering profession.

Plasser & Theurer has therefore developed the EM SAT track survey car that works independently of the tamping machine and which has already been presented in countless publications and needs no further description here. The EM-SAT enables the technologically necessary sequence of operations: measuring –

Cost drivers	Meaning
Initial quality of permanent way	The initial quality determines the behaviour of the track over its entire service life. It cannot be improved later!
Substructure quality	Dependent on traffic loading, differing substructure qualities have a strong influence on the life-cycle costs of permanent way. On low-traffic lines the life-cycle costs of the permanent way rise by a factor of 3 in the case of very poor substructure quality compared to a factor of 2 with good quality substructure, however on main lines with heavy traffic this factor rises by a factor of 8!
Turnout density	In terms of life-cycle costs, a turnout with a diverging radius of R = 500 m and an actual length of 50 m is equivalent to about 450 m track of the same rail type – a proportion which should encourage careful handling when turnouts are installed.
Radii	The life-cycle costs of curved track with a radius of R = 250 m are three times the value of a straight track section of the same length.
Operational hindrance costs	On main lines with heavy traffic the operational hindrance costs can account for a third of the life cycle costs of plain line track.
Traffic load	Traffic load is a major cost driver, although its effect can be kept in limits when using correctly dimensioned permanent way for the respective traffic loads. Then in the best case the costs will rise in a linear manner. However, if the dimensioning of the permanent way does not correspond to the actual traffic loading, this will result in over-linear cost growth.
Quality of the rolling stock	Taking into consideration the effect of locomotives on the track and above all the track-friendliness of the locomotives, this accounts for 5% in some extreme cases up to 10%, of the track's life-cycle costs.

Table 1: Cost drivers for railway permanent way

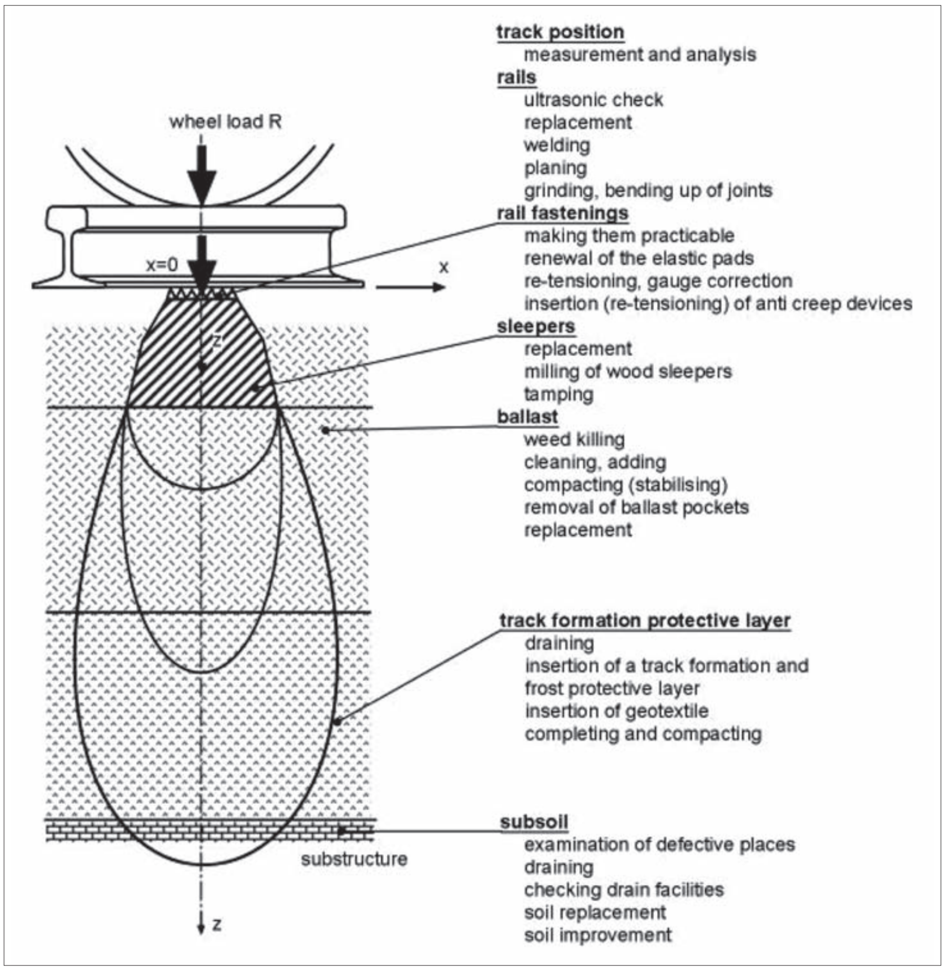

Fig. 5: Assuring the track quality by maintaining all components

Fig. 6: EM-SAT with integrated fixed-point direction-finding unit

evaluation – planning – implementation. Above all, the final track geometry is not determined by the machine operator but by the engineer responsible for the tracks.

The latest standard of development of mechanised surveying was presented at the VDEI Surveying Conference in October 2005 [16]. The discussion revealed that even today systems that are installed directly in the tamping machine cannot perform properly without prior surveying work.

The major further developments of the EM-SAT are:

▷ Incorporation of the non-contact fixed-point measuring device into the machine (Fig. 6)
▷ Satellite-assisted surveying
▷ Ballast profile measuring system
▷ Catenary measuring system

Two systems were modified which work in direct connection with the tamping machine.

▷ The CAL curve laser system is an additional device for the tamping machine to work according to fixed points. It consists of a laser trolley and a laser camera on the machine and an on-board calculator with EM-SAT software. The system is intended for the first and second tamping pass following renewal or ballasting work and the tamping machine is somewhat restricted by the laser operation. It is also not possible to plan the tamping operation in advance (placement of ballast, etc.).
▷ The CAL-SAT performs a similar function like the CAL curve laser system but is a separate machine which is coupled to the tamping machine for transfer travel and works independently with its own power unit.

4.1.1 High capacity tamping and track stabilisation

Thanks to the introduction of the continuous action three-sleeper tamping machine, high quality work can also be performed cost-efficiently in very short intervals between trains. The 09-3X tamping express has proven reliable not only on passenger traffic lines but is also in successful operation on the freight railways in North America and on the heavy-haul railways in South America, South Africa and Australia.

In summer 2005 the first 09-4X Dynamic four-sleeper tamping machine went into operation in Austria. This machine achieves average working speeds of 2400 m/h and peak performances of 2600 m/h. It can be switched over at any time from four-sleeper tamping to two-sleeper or even single sleeper tamping (Fig. 7).

It has proven to be well worthwhile to combine the continuous action tamping machine with dynamic track stabilisation (09 Dynamic). Since 2000 more than 25 % of the two hundred 09 tamping machines were supplied as 09 Dynamic models. This tendency is rising and on present deliveries the proportion has already reached 40 %.

4.1.2 Ballast management

Ballast profile measurements using the EM-SAT on Austrian Federal Railways confirm: if the ballast lying in the track could be better distributed, it would be possible to save large quantities of new ballast in conjunction with track maintenance work. This finding has produced the result that since 2005 two BDS ballast distribution systems have been in operation together with mechanised track maintenance trains (Fig. 8). These ballast distributing and profiling machines are equipped with a powerful ballast collection system which picks up surplus ballast from the track and stores it in a large hopper. In order to keep up with the Tamping Express high-capacity tamping machines, the machine carries two sweeper and collection units positioned one behind the other. If large quantities of ballast are to be picked up, MFS material conveyor and hopper units can be added to the system at any time. The collected ballast can be re-distributed in areas where there is a shortage of ballast. With consistent operation of the machines to save ballast, the machine can pay for itself within a period of two years [17].

4.2 Maintenance of points

The universal machines of the UNIMAT 09 series combine the proven advantages of the continuous-action plain line tamping machines, namely continuous forward motion and cyclic tamping, with those of the most up-to-date point tamping

Fig. 7a: Operation as a continuous-action four-sleeper tamping machine

Fig. 7b: Operation as a continuous-action two-sleeper tamping machine

Fig. 7c: Operation as a continuous-action single-sleeper tamping machine

machines with three-rail lifting and four-rail tamping.

In the era of high-speed and high-capacity traffic only very little time remains for track work. The machines have to provide maximum output in the minimum time available. The Unimat 09-475 4S is the basic version of a continuous-action single sleeper point tamping machine, the Unimat 09-32 works in Duomatic (2-sleeper) mode. Plasser & Theurer has also introduced machines of the UNIMAT 09 series onto the market with integrated stabilisation units. In this model the trailer of the UNIMAT 09 carries the proven stabilisation units well-known from the DGS 62 N dynamic track stabilizer .

This combination achieves an optimum utilisation of the track possessions with additional perfection of the track geometry. The Unimat 09-32 4S Dynamic can work flexibly in the worksite because it can be brought onto the worksite quickly and taken out again speedily. When working with groups of machines there is a time delay between the start and end of operation of each machine. Here all units work simultaneously which shortens the time spent in the work area. The incorporation of dynamic stabilisation, even for point maintenance, also helps to lower the maintenance costs.

Fig. 8: Better distribution of ballast using the BDS system

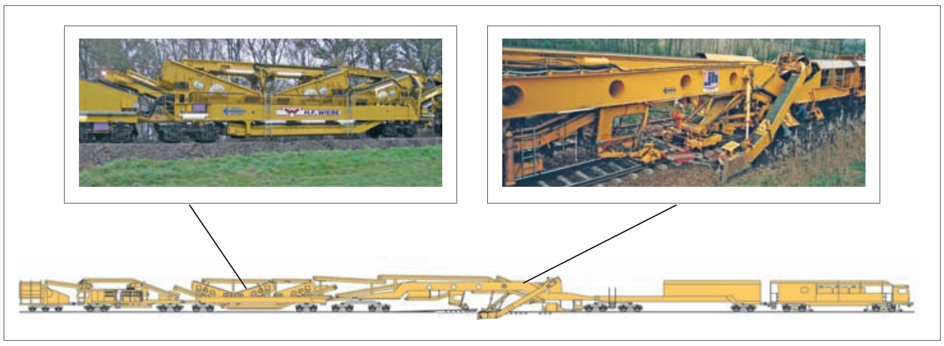

Fig. 9: RM 800 Super 3S with three screening units and adjustable excavating chain

4.3 Ballast cleaning

Increasingly varied demands are being placed on modern ballast cleaning machines. A high working speed to better utilise short train possessions, high cleaning quality, the recycling of a large quantity of ballast, which is a costly resource, and finally versatile application of the machine are required.

These demands led to the development of the high-capacity ballast cleaning machines with double screen, models RM 800 to RM 2003. By doubling the screening unit it was possible to achieve the higher output of up to 1000 m³/h with full cleaning quality.

Machines with three screening units offer a further increase in output. The first such machine, the RMW 1500 with star screen car, has been in operation since 2005 [18].

The machine is equipped with two excavating chains. The first chain removes the top layer of ballast down to a maximum excavation depth of 400 mm from lower edge of sleeper, the maximum excavating output is 500 m³/h. The second excavating chain removes the lower layer down to a maximum depth of 1100 mm from top of rail. This chain has an excavating output up to 1000 m³/h. The maximum excavating width of the first chain is set at 3500 mm. The second chain is designed for width of 4–5 m, depending on the length of the cutter bar, and a depth of 1100 mm below top of rail. Feeder plates allow the width to be extended by 600 mm maximum.

The second three-screen machine, the RM 800 Super 3S, was on show at the iaf 2006 in Münster (Fig. 9). The special feature of this machine is the high-capacity excavating chain with steplessly adjustable width, a principle that already proved to be very reliable on the first RM 800.

4.4 Combination of ballast cleaning and track renewal

The complete renewal of a section of track requires both the cleaning of the ballast bed and the exchange of the skeleton track. According to UIC regulation this must be performed exactly in the following order: in the first working operation the track ballast is cleaned using a ballast cleaning machine and then the skeleton track is exchanged using a track renewal machine.

Since these two operations can practically never be performed in the same track possession, the track has to be made ready for traffic again after the ballast cleaning using tamping machines or an MDZ mechanised maintenance train to ensure unhindered passage of trains between the two phases of construction. Track renewal is later performed in a second track possession, after which the MDZ will also have to produce the correct final track geometry.

Line improvement on this scale requires precise logistic planning over a longer period of time. A number of heavy-duty machines together with the respective operating and worksite personnel have to be co-ordinated and brought to the worksite at the right time. Two longer track possessions, usually on two consecutive weekends, are required to be able to perform all operations.

The capital expenditure associated with renewal work on this scale are correspondingly high. In addition to the costs for planning, machines and staff, worksite security, etc., there are the respective operational hindrance costs for two complete track possessions to be considered. Nevertheless, this is a generally accepted technology today which has been in use around the world for many years – not least for lack of realistic alternatives.

The combination of ballast cleaning and track renewal in one machine has already been discussed for some time. Above all, the railway administrations want such a technology because the associated savings potential would be enormous.

These requirements are now met by the RU 800 S, a continuous action ballast bed cleaning and track renewal train (Fig. 10). 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 the associated technological, logistic and above all economic advantages.

The front ballast excavating chain designed for an excavation width of max. 3500 mm (with feeder plates) is positioned in a construction gap almost 11 metres long between removal of old sleepers and installation of new sleepers. This guarantees excavation over the entire width of the track which ensures that an accurate ballast bed can be prepared for the new sleepers. On the other hand, it allows extremely simple excavation of the ballast bed materials in restricted situations, for example, near to station platforms. The ballast is also consolidated before the new sleepers are laid. This means there is no need for the first tamping pass after the RU 800 S. The shoulder ballast is picked up in the rear section of the machine using additional shoulder cleaning units. All the excavated ballast is taken to a high-capacity double screening unit and cleaned. The spoil is taken to the front and loaded into MFS units, the cleaned ballast

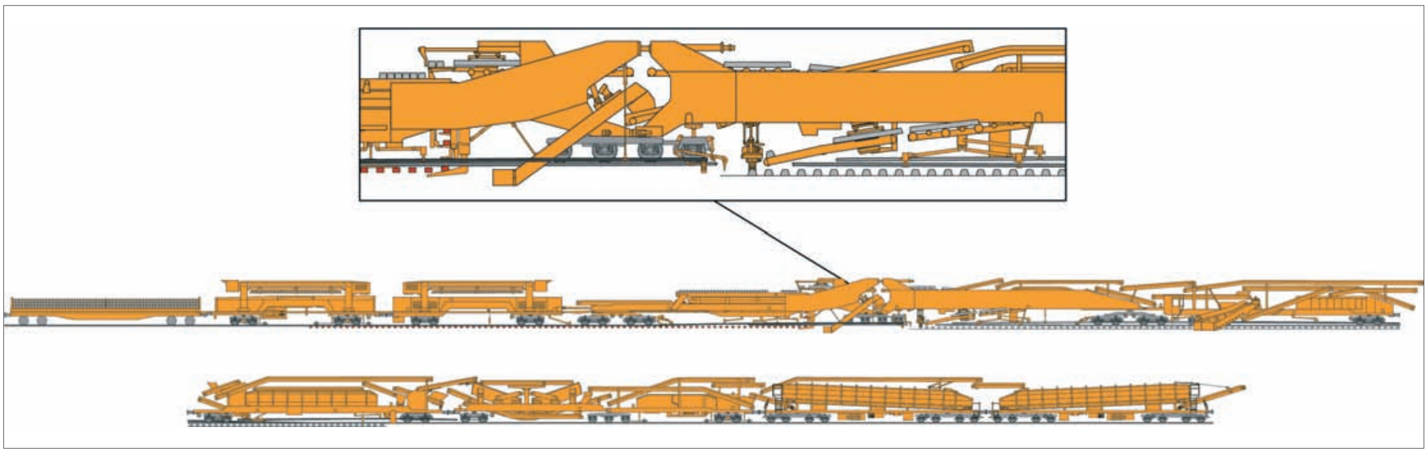

Fig. 10: RU 800 S – track renewal and ballast cleaning in one machine

is taken on conveyor belts to an intermediate storage hopper.

The treatment of ballast was very carefully designed in the course of development of the RU 800 S. The ballast hopper on the machine is a central element. This hopper is equipped with a continuous floor conveyor belt for simple loading and unloading. Material is stored here, providing adequate supply of ballast at the start of the worksite and emptying of the transport systems at the end of the worksite. From here the ballast chutes fill the newly laid skeleton track with ballast. The track is filled with cleaned ballast and also with new ballast, if required. Heaps of ballast next to the track will therefore be a thing of the past and new ballast can be added in any desired quantity from the specially adapted MFS units. In principle, complete ballast exchange is also possible: total excavation of the ballast bed material and placement of new ballast.

The machine was designed primarily for track renewal with ballast bed cleaning. Other types of application are possible beyond this. The control of the individual machine sections are designed to save energy, so that those units not required do not have to be put into operation.

4.5 Installation and maintenance of catenary

Just as for track maintenance, the installation and maintenance methods for overhead catenary also need to provide high capacity, precision and reliability. The aim when using a combined machine technology is to achieve more cost-efficient working method and to utilise further potential rationalisation [19]. Moreover, it also guarantees a consistent high quality and the best possible work safety. The quality features are documented continuously and in reproducible quality by a new measuring technology on the work machines even during the working process.

4.5.1 Installation of catenary

The development of the continuous action catenary renewal machines of the FUM series was a substantial step forwards for the installation of catenary. As early as 2003 such a machine went into service on DB Bahnbau with great success [20]. The FUM machines install contact wire and carrying cable immediately with the final tension. This is an enormous improvement in quality and the time required for construction was reduced to one fifth.

An FUM 100 (firm's name Gemma) was also operated by the Dutch contractor Strukton Railinfra bv with its German partner Fahrleitungsbau GmbH on the 160 km long double track freight traffic

Fig. 11: FGW 10.010 catenary during assembly work in Zurich main station

line called the Betuweroute from the port of Rotterdam to the German border [21]. The catenary system has to be installed in the shortest possible time as the two track line is scheduled to go into operation at the end of 2006. Using Gemma two times 100 km of catenary will be installed and the machine easily manages three spans per day each with 1200 to 1400 m length. The record output so far was the installation of 6000 metres of catenary system in one day. The project is the first 25 kV electrification in the Netherlands.

4.5.2 Motor tower car with freely turning telescopic work platform

A great deal of development work goes into the machines for assembly and maintenance of catenary. The MTW 100 motor tower cars are also in operation on DB Bahnbau, which perform the tasks of maintenance, servicing, inspection, safety checks, fault elimination, assistance during renewal and installation. The high degree of freedom of the freely turning elevating work platform allows the assembly staff fast and optimum access to the working points. The combined work technology with contact wire holder and crane together with remote control of all functions from the elevating work platform or from outside the track, makes the work easier and enables higher working outputs. Today, various additional devices such as the contact wire measuring unit are standard equipment.

4.5.3 FGW platform car

The FGW platform cars are used for the removal, repair and assembly of catenary. Time and manpower can be saved by using these new self-propelled work vehicles. They help to simplify the work sequences and provides greater safety for the operating crews.

The special feature of the FGW 10.010 platform car (Fig. 11) is the fully hydraulic elevating platform split into three sections. The complete platform can be raised and when it reaches the catenary, the two smaller sections can be displaced and lifted again additionally. This enables staff to work efficiently at the catenary since both carrying cable and contact wire are easy to reach. A hydraulic holding device for contact wire and carrying cable, a dropper measuring unit with display on the platform, a contact wire observation and measuring unit and the enclosed crew cabin are included in the equipment of this vehicle.

5 Summary

High capacity, precision, reliability are the demands placed on modern machines for track maintenance. High capacity enables low unit costs and less disruption of the train services. Precision is necessary to keep the level of dynamic forces low, as shown by the various methods of permanent way calculation. Reliability is also the key to low costs and undisrupted operation. New developments that were presented at the iaf 2006 in Münster fulfil these requirements. For instance the high capacity tamping machines for either one, two or four sleepers or the new ballast cleaning machines with three screens and the combined ballast cleaning and track renewal machine. Similar rationalisation effects, such as those achieved in track maintenance, have also been gained using up-to-date catenary renewal machines which were also on show.

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