Slab track surveying and set-up - a system concept

Efficient and high-quality manufacture of slab track entails using specific methods for surveying and setting up that function reliably in construction site conditions. The methods described in the article can be used both for all monolithic designs (e.g. Rheda) and for slab track designs with elastic-mounted sleepers (e.g. Bözberg, Euroblock); at the same time, they open up new possibilities for construction site logistics. These industrial-type working methods were successfully used to lay 126 km of slab track on the new Cologne - Rhein/Main line.

Surveying

Surveying work on the new Hanover - Berlin high speed line proved that the behaviour of track displacement monitoring control points (GVP = Gleisvermarkungspunkte) mounted on catenary supports is relatively unstable over the course of construction. Given the tight manufacturing tolerances with regard to internal track accuracy, it is the unstable control point network which leads to extreme difficulty in meeting the required accuracy of track positioning. Independent measurements of individual track points using the arbitrary stationing method produced measuring differences of up to 5 mm. These differences occurred particularly in areas of transition between instrument stations.

In 1999, the Stuttgart University Institute for Geodetic Applications in Civil Engineering (IAGB = Institut für Anwendungen der Geodäsie im Bauwesen) carried out a comprehensive analysis of basic surveying principles for slab track construction work. It was found in the course of this project that without special additional measures the existing control points (GVP) were scarcely adequate as a basis for slab track construction work.

Track reference network

While preparing construction work for the Cologne - Rhein/Main line, a surveying approach using track reference points (GRP = Gleisreferenzpunkte) was established in cooperation with, and based on the research results of, the IAGB [1]. This surveying approach is based on its own reference point network with fixed points in the concrete troughs. This has several advantages:

- These track reference points (GRP) are formed by M12-type threaded pins incorporated in the side walls of the troughs, thus representing the most stable reference for track production.
- The position of the control points (GVP) varies over the whole construction process due to ground settlement and other influences. They should therefore be considered as “changing fixed points”. Thus, to keep the track-laying process free of these changes, the track reference point (GRP) network is used.
- The total station or reflector is set up at track reference points by means of special tripods following the forced centring method. In contrast to arbitrary or “free” station positioning, this system provides repeatable station positions, integrating the respective neighbouring track reference points as measuring stations.

A specific network will be measured, based on these track reference points (GRP). The network adjustment scheme is outlined in Fig. 1. When carrying out the network adjustment, the track reference points (GRP) are calculated as a rigid network with elastic links to the control points (GVP) thus resulting in the highest possible stability of the GRP-network used later on to adjust the actual track position.

Special tripods

The special tripod is clamped against the screw bolt with the base plate. The tripod is then levelled by means of the ball joint whose centre is situated 40 mm above the lower edge of the support plate. This levelling process is carried out in two phases: first (coarsely) by means of a circular bubble and after that, by means of a precise spirit level or the relevant centring device of the total station. These special tripods have the following advantages:

- Every forward and back station can be incorporated in the measurement thus reducing the error in intermediate areas between pairs of instrument stations to a minimum.
- Thanks to the use of forced centring, coordinates of the instrument stations are known. Costly signalisation and pointing to 6 - 8 control points (GVP) to fix the free stations can thus be avoided.
- The clamp arrangement ensures that the tripods are very well connected to the subsoil so that even short period vibrations caused by construction site traffic do not affect instrument station quality.
- Thanks to the stable connection to the ground, acceleration and deceleration forces occurring with motorised total stations can be absorbed.

Figs. 2a - 2c show the individual steps in detail.

Measuring trolley and Hergie system

Track measurement coordinates are transferred to the track to be adjusted using a Sinning measuring trolley and special software (the Hergie system) for high-precision track adjustment in real time, developed in cooperation with IAGB. The measuring trolley is equipped with a reflector, a superelevation (cant) sensor, a track gauge sensor and an industry-standard PC with local 12V (car battery) power supply. Communication between measuring trolley and total station is ensured by a standardised data radio link. In order to improve the workflow, a second display is mounted on the trolley enabling operators to follow and read the adjustment information both left and right of the track at the same time (Fig. 3). From any position of the measuring trolley, the specially developed software determines the actual track position, the superelevation (cant) information as well as the track gauge, and compares this data with the theoretically calculated track alignment values. The theoretical values for each position of the measuring trolley are calculated from the gradient (longitudinal profile), the curve alignment, the superelevation (cant) alignment and the coordinates of the tangent points. Clothoids with linearly increasing cant gradients and curvatures as well as Bloss curves with gradual non-linear changes of cant gradient and...
curvature are used as transition curves.
An important advantage of the procedure is
that the measuring trolley does not have to
follow any particular pattern of points but
can be positioned at any required point on
the track.
Values needed to adjust the track such as left
and right rail heights as well as lateral position
correction are displayed on screen at a large
scale and to 0.1 mm accuracy. Moreover, the
km chainage (“km station”), the measured and
the theoretical superelevation (cant) as well
as the track gauge values are available in any
individual point.
Depending on the quality required and the
available timescale, the values supplied to the
measuring trolley will be updated at intervals
of about two seconds in tracking mode and
five seconds in precision mode. The opera-
tion team can immediately observe the posi-
tion and height adjustment of the track wit-
 hin the 0.1 mm accuracy range.

Adjusting and fixing system

Starting from the standardised manufacturing
procedures in use up to 1998, especially on
the Hanover - Berlin high speed line, the pro-
blems are now described in detail and the
new solutions are explained.

Initial situation with the RHEDA system

Up to now, monobloc sleepers have been
used primarily with the RHEDA system.
Horizontal and vertical screw spindles are
incorporated in every second sleeper in
order to adjust the track height. Because
vertical spindles do not provide any lateral
fixing, track adjustment by using this method
can only be ensured by bracing the track
assembly against the side walls of the
concrete trough. The principle of vertical and
horizontal adjustment and fixing of position
of the track by means of the vertical spindles
and the horizontal screw embedded in
alternate sleepers are shown in the cross sec-
tion (Fig. 4a) and the support scheme
( Fig. 4b).

Fig. 5a illustrates the support and clamping of
the vertical spindles. It is easy to see that an
accurate horizontal adjustment based on
these supports is hardly possible. If lateral for-
ces are applied, a moment will build up in the
vertical spindle which will be released spont-
aneously when static friction is exceeded,
thus preventing continuous horizontal
adjustment of the track.

Because of the highly elastic reaction of the
whole system, the lateral screws shown in Fig.
5b need to be used in order to brace the
track assembly against the concrete trough
on both sides of the sleeper. This implies that
two screws must always be used for the late-
ral adjustment of the track. One detail which
has not received much attention up to now is
the free play of the rail within its fastening.
The manufacturing tolerances of sleepers,
baseplates and of the rail itself require an ave-
rage clearance of 1 mm. In case of accidental
unfavourable addition of individual
tolerances, this clearance may increase to up
to 2 mm. This aspect is especially important
when replacing rails at the end of their life or
pulling them back after welding.

Track alignment by means of the above-
mentioned vertical and horizontal spindles
requires several iterative adjustments
because the elastic mounting and the
resulting residual stress within the track will
always affect previously adjusted track as the
work proceeds.

Varying rail lengths caused by changes of rail
temperature lead to additional problems
which cannot be managed with this
adjustment system. It happened several times
that with significant rail temperature
differences (up to 40°C between day and
night) the already adjusted track builds up
high stresses which are released
spontaneously when adhesive forces are
exceeded. Thus a further adjustment, with all
its disadvantages in terms of delaying other
construction work, is required.
After removing the vertical spindles, the holes in the sleepers must be closed up with sealing mortar. The alternation of supported/spindled sleepers and those hanging on the rails as well as the interaction with the elastic link between rail and sleeper lead to systematic height differences in the support of the rail.

Aims for the development of the new adjustment system

On the basis of this experience, the following aims and requirements were fixed for the development of the new adjustment system. Manageability of the thermal expansion of the rails

Due to temperature variations between day and night or between sunny and cloudy weather, the length of rails varies significantly. When using 120m long rails, their length may vary by up to 40 mm. The adjustment and fixing system must therefore allow for these expansion effects while fixing the rails both horizontally and vertically.

Adjustment system free of elasticity

The adjustment and fixing system has to be as free as possible of elastic behaviour. With conventional systems, supports are generally used which absorb the moment of the load. In order to keep weight as low as possible, higher elastic deformation is accepted with loading due to adjustment and fixing. However, these deformations cause elastic behaviour in the track which is to be adjusted.

In order to ensure that the adjustment process is as efficient as possible, the new adjustment systems must be designed to act exclusively via pressure forces without any effect of moments.

High position and height adjustment accuracy

The adjustment and fixing system should enable the track to be moved smoothly and without jerkiness, both horizontally and vertically, to an accuracy in the region of 0.1 mm, and to be maintained in this position.

High loading capacity in order to enable the use of standard systems

The adjustment and fixing system should withstand axle loads up to 20 tons on the adjusted track to enable the use of standard track lining devices (modified tamping machines). These loads must be absorbed in spite of the very high positioning accuracy. This aspect is especially important in long single-track tunnels where the single track will also be used for the supply of construction material.

Constraint-free adjustment

In order to achieve a continuous track alignment, the rail is considered as a flexible curve. The adjustment system should avoid any constraints causing high residual stresses in the aligned track.

Simple operation and practical use

In contrast to conventional track adjustment frames with weights of up to 100 kg, the new system should be designed to be as light and flexible as possible. The weight of the individual alignment tool should be under 5 kg to enable its efficient handling and use. The adjustment wedges are designed to enable the alignment systems for a 200m track section to be stored and transported in one wire-mesh case only.

Process-oriented for multi-purpose application

Fig. 4a: Cross section of the RHEDA system including spindles incorporated in the sleepers

Fig. 4b: Support scheme with the RHEDA system

Fig. 5a: Sleeper spindle on its seat

Fig. 5b: Lateral screw bracing against the side wall of the concrete trough
The adjustment procedure should be designed to be independent of specific slab track features such as different systems or cross sections. It may be used for both monobloc and twin block sleepers as well as for monolithic or elastically supported sleepers and sleeper blocks.

**Highly reproducible quality**
The procedures as a whole are designed to ensure reliable and highly reproducible quality and performance throughout all manufacturing steps on site.

**Maximum structure clearance for the placement of lean concrete**
The adjustment system is designed to offer maximum freedom of movement for subsequent pouring of lean-mixed filling concrete. Especially when using concrete mixing machines, obstructionless operation is an essential requirement.

**Independent support for the left and right rails**
The independent support of the left and right rails is of particular importance for special applications such as switch and crossing work or for expansion joints. Because the whole system is designed to treat the left and right rails separately, it can also be used in switches without any restriction.

**Development steps**
In the first step, a simple lifting wedge was developed and used for top correction on the construction of the new Hanover - Berlin line (Fig. 6a). In this project, tracks were aligned by means of a tamping and lining machine. The wedges were positioned under the adjusted track near the tamping head and then tightened. Performances up to 950 m per working shift could be reached by using this procedure. In the next step, these lifting wedges were additionally equipped with horizontal adjustment facilities and then used for setting-up six switches and 1000 m of branch line track in the Wolfsgruben tunnel (St. Anton, Austria) (Fig. 6b). Later, this system was further developed for the new Cologne - Rhein/Main line.

**Loading tests**
Extensive preliminary tests were carried out on a test track at the Rhomberg company yard in order to ensure the correct functioning of the system, especially with regard to lateral stability. The track was set up on a carrier plate with a lateral tilt of 12% (= 180 mm cant). The track was then adjusted and exposed to lateral forces. Track deformations were monitored to an accuracy of 0.01 mm at the point of application of the load as well as at both adjacent support points on the rail, at the wedge and at the concrete supporting structure, by means of dial gauges (Fig. 7).

Forces of 1 kN, 2 kN, 3 kN, 4 kN and 5 kN were applied and released. In spite of a 2 mm deformation with 5 kN, the residual deformation after release was only 0.3 mm. After this test, the track was exposed to an oscillating load of about 20 kN and to vehicle movement. The residual deformations of 0.3 mm were further reduced through these vibrations. This test proved the stability of the adjustment system to be extremely high and the sensitivity of the adjusted track to vibrations, especially during subsequent pouring of concrete, to be very low. The concept of the constraint-free adjustment system treating the rail as a flexible curve responds benignly to loads resulting from the construction process. The experience gained in these tests was confirmed throughout the Cologne - Rhein/Main construction site.

**RSS setup system on the new Cologne - Rhein/Main line**
The RSS survey and set-up system created by Bahnbau Wels has been used for the construction of 1.26 km of slab track for the new Cologne - Rhein/Main line, or 50% of the whole line. This track alignment system is based on the following principles (Figs. 8a - 8e):

- The rails themselves form the ideal curve template for an accurate adjustment of the track.
- Supports are set up with lifting and slewing wedges in the space between every third sleeper, enabling accurate horizontal and vertical track adjustment and fixing directly on the rail.
- The wedges are placed directly on concrete supports which are mounted on the concrete slab base. Set on these nonelastic supports, the behaviour of the rails as curve templates can thus be optimally exploited.
- The lateral forces needed for track adjustment and fixing can be discharged by pure pressure forces directly into the subsoil without any additional measures. Even with cant values of 170 mm, this does not present any problem.
- When using long rails, these lifting and slewing wedges are additionally equipped with longitudinal sliding bearings, thereby allowing thermal expansion of the rail without influencing its position and height.

The individual components are described as follows.

**Concrete supports**
Pre-fabricated concrete supports whose qua-
ility corresponds to lean concrete are used as the foundation of the set-up system. The height of these concrete supports can be adapted to the relevant track cross section.

Lifting and slewing wedges
Several different types of wedges are available for the system.

Adjusting wedges specifically optimised for use with temporary construction rails have been used in contract section C. Each adjusting wedge can be clamped onto the temporary rail enabling the wedges to be transported at the same time when the temporary rails are moved. Because of the short length of the temporary rails (18.2 m), no longitudinal slide is needed with this system. Both screw spindles can be operated from one side in order to adjust track position and height. The minimum height clearance between the rail foot and the upper edge of the concrete support is about 80 mm (Fig. 8b). Wedges with longitudinal sliding bearings are used in track sections with long welded rails (contract section B) (Fig. 8e). This type has an optimised height clearance of about 60 mm, ensuring vertical adjustment by means of the exterior (visible) spindle and horizontal adjustment by means of the interior spindle. This wedge offers a height of lift of 30 mm, a horizontal correction of ±15 mm and up to ±30 mm of longitudinal movement of the rail.

Manual lifting/slewing unit
Simple, manually-operated lifting/slewing units consisting of three rail-lifting jacks are used for preliminary coarse adjustment. By means of this adjustment unit, the track is brought into its appropriate vertical position on both the left and right sides. A slewing jack provides for a very exact horizontal position (Fig. 9). This apparatus ensures preliminary adjustment to an accuracy of about ±2 mm.

The construction process
After distribution of the concrete supports and the lifting/slewing wedges, the prefabricated track assembly is lifted using Mammut equipment and, with orientation in relation to the concrete trough and its side walls, is pre-laid on the prepared supports and wedges to an accuracy of about ±20 mm horizontally and ±20 mm to 0 mm vertically.

By using the Hergie measuring system in a first surveying stage (pre-adjustment), the track is brought approximately into its correct horizontal and vertical position to an accuracy of about ±2 mm by means of the manual lifting/slewing unit (see Fig. 9). The wedges are locked beneath this unit enabling the track to be supported accordingly. Because the track is already relatively free of stresses, the fine adjustment can be achieved with the spindles of the wedges alone. With the aid of gravity, these screws are sufficient to enable jerk-free horizontal and vertical adjustment and fastening of the track to an extraordinary accuracy of a few tenths of a millimetre (see also Fig. 3).

Where cant values exceed about 100 mm, supporting bolts are welded on the inner side of the sleepers and braced against the side wall of the concrete trough. However, these supporting bolts only form an additional safety measure to prevent the track from slipping inwards during concreting on highly superelevated track sections.

Survey data from the fine adjustment process are suitably logged and are available for track quality documentation purposes as well as for release of the track for concreting (Fig. 10).

Construction site logistics
In the absence of adjacent track enabling access, slab track in contract section C (awarded to Walter Heilit Verkehrswegebau) has been built for the most part using temporary construction rails.

The 15 - 18m long rails are laid down and mounted on the prepared sleepers. After the lean concrete has set, they can be removed and reused. About 1700 m of temporary track was necessary to equip one construction team. This method allows flexible assembly of slab track, independently of adjacent tracks which would otherwise be needed to bring continuously welded rails to the construction site and to unload them on site. Fig. 11 shows a special vehicle used to remove...
the temporary rails. With this procedure, continuous welded rail is introduced only at a very late stage, thus offering the advantage of preventing contact between rail and wet concrete at any stage of construction. Rail surface defects which could result from contamination by concrete are thus eliminated.

Another advantage of this construction procedure is that the already concreted first track is available for the laying of the second track along its full length. Tracks (as shown in Fig. 11) as well as concrete can be delivered using the completed track. Parallel construction roads or costly transport of rail are thus avoided.

Besides the developments described in this article, slab track technology offers significant potential for the integrated planning of construction work and of specific manufacturing processes.

References


Vermessen und Einrichten von Festen Fahrbahnen - Systemkonzept


Mesurages et aménagement de voies sans ballast - Concept du système

Pour être efficace et de haute qualité, la construction des voies sans ballast nécessite, en matière de mesurage et d’aménagement, des procédés spécifiques qui fonctionnent de façon sûre dans les conditions des chantiers. Les méthodes décrites dans cet article peuvent être utilisées sur tous les types de construction monolithiques du système Rhéda et sur les types de voies sans ballast comportant des traverses à pose élastique (tels que Bözberg et Euroblock). Elles permettent, en outre, d’ouvrir de nouvelles voies pour la logistique des chantiers. Le recours à ces déroulement industrialisés du travail a permis de construire, avec succès, 126 km de voies sans ballast sur la ligne nouvelle Cologne-Rhin/Main.