DB Netz uses satellites to locate track in three dimensions

GEOMETRY Satellite surveying enhanced by reference points on the ground is now so accurate that it can be used to define the absolute position of track to ±10 mm accuracy, allowing contractors' tamping and lining machines to produce track geometry within ±1 mm of optimised calculated values.

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Since January 2006, the phased introduction of the DB Reference System, which is based on satellite positioning in three dimensions and embraces the European Terrestrial Reference Frame (ETRF'89), has started to supersede the manual track surveying methods introduced on DB more than 30 years ago.

Instead of having to maintain the accuracy of 1·2 million geodetic track datum points under the old system, only around 7 000 reference points will need to be maintained in the future to enable the absolute location, level and cant of a track at any point on the German network to be determined within an accuracy of ±10 mm.

The new reference points can be surveyed and marked about seven times faster, and with greater accuracy, than the existing geodetic reference points. They can also be checked faster, and where necessary replaced with a higher degree of accuracy.

When the existing track surveying system was first introduced by Deutsche Bundesbahn 35 years ago, the track survey chart provided the interface between the work of the surveying and permanent way departments.

However, systematic track faults have occurred from time to time because the stability of the geodetic track points could not be relied upon. Tamping machines used compensating methods based on extreme extrapolation to determine the geometry needed for a particular site.

When this happens, the track geometry falls a long way short of meeting today's requirements as regards speed and comfort. However, remedial action to improve the defective geodetic track points would require a great deal of time and money. Hence the switch to satellite surveying.

Satellite-supported surveying

As a basis for determining the precise location of railway infrastructure, DB adopted ETRF'89 in 2000, forming the basis of a uniform, three-dimensional co-ordinate system known as the DB Reference System (DB-Ref) [1,2]. The objective was safe and economical provision of the required track network data (Fig 1).

The economic justification for satellite-supported track surveying is achieved mainly by reducing the number of geodetic track points, but also by the reliable reconstruction of defined target track geometries using a point grid density of some 40 to 80 m on both sides of the tracks. This gives a point quantity of about 34 geodetic track points per route-km, equivalent to around 1·2 million geodetic track points for the entire network of 34 121 route-km.

Reconstructing the geodetic track points would incur a high capital cost plus ongoing maintenance expenditure, making a good economic case for switching to a satellite-based approach. DB Netz decided to create a reference network on a 4 km grid on the basis of ETRF'89. Compared to the previous method of track surveying, the benefits of satellite-supported surveying are:

- one reference point for a maximum of 4 route-km requiring fewer than 7 000 reference points to be calibrated;
- a track measuring output of up to 10 track-km per shift compared to 1 track-km per shift;
- errors inherent in the old track

Plasser & Theurer has worked with DB and ÖBB to develop a measuring train. A laser chord links the rover unit to the EM-SAT vehicle behind, which has a roof-mounted satellite receiver antenna.

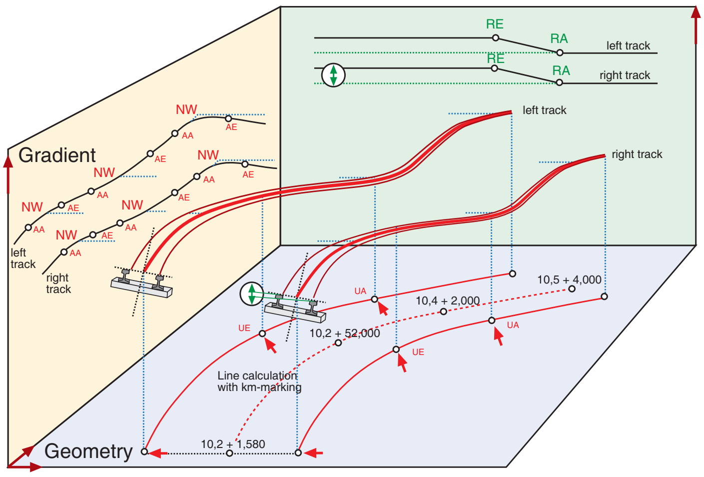

Fig 1. The Deutsche Bahn Reference System provides a three-dimensional representation of the track position.

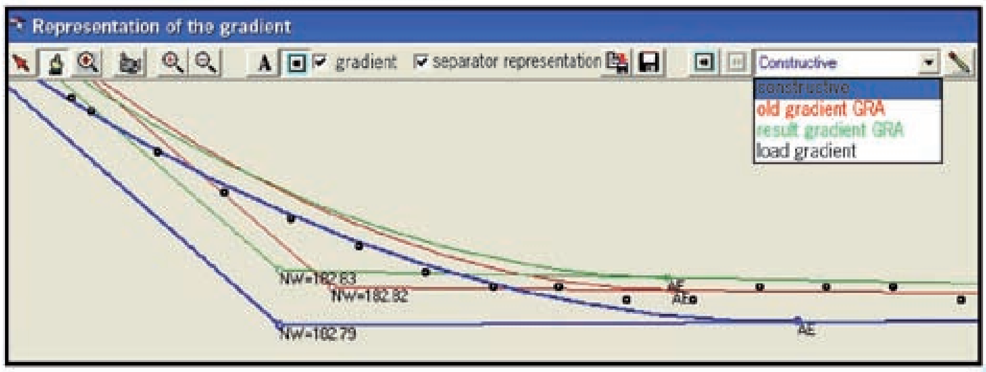

Fig 2. Atrek provides automatic gradient calculation with interactive processing functions.

surveying system are eliminated;
- much less maintenance of the reference points is required;
- it is simple to reconstruct a reference point immediately, even in the event of loss of reception.

DB Guideline 883 applicable from January 1 2006 ruled that all new layouts drawn up by the surveying department must use the new reference system. However, a basic requirement, besides compatible data, is a functional satellite navigation system. In addition to America's GPS and Russia's Glonass, both available on the market, the plan is to use the Galileo satellite network currently being developed in Europe.

Surveying using Gnbahn

Initially, the measuring system for kinematic track surveying was developed using Geo++ -Gnbahn software. This allows the complete recording in real time of the track geometry in the form of three-dimensional co-ordinates, including cant and track gauge with high accuracy and high spatial density in one operation.

The multi-station Gnnet-RTK (real time kinematic) system allows precise determination of 3D co-ordinates using high-quality satellite receivers. The Gnbahn/PM software is used to measure, check and view all measured data, and to perform a track-related technical calculation with a graphical operator interface. The performance range of Gnbahn not only allows the measurement of the actual track geometry but also identifies any faults in alignment, level, track gauge and cant compared to the known target track geometry.

The user interface performs a check on the track surveying and recording in real-time. Gnbahn/PM runs on a pen-top calculator which is connected to the gauge-centred rolling surveying system carrier known as SurVer.

In addition, a connection to SurVer is set up on a nearby reference point using a GPS reference station with an appropriate communication link; this can be GSM, GSM-R or even analogue radio. The objective is to raise the quality of the co-ordinates using a differential method.

This produces a substantial improvement in accuracy, bringing it into the sub-centimetre range. Gnbahn/PM has various graphic windows in the main display which show position, target layout, deficiency in line and level, cant and track gauge from preceding measuring runs.

If no target layout is available, Gnbahn offers the possibility to establish a new layout via a three-dimensional record of the actual track geometry, creating a simultaneous layout representation using spline functions. The continuous flow of track co-ordinates is processed dynamically by appropriate algorithms, and the resulting splines describe the actual position of the track optimally at all times.

Where no target layouts or gradients exist, we can use the Atrek evaluation software for automated layout recognition, which was developed by Technet GmbH for such circumstances. Using a graphical representation, Atrek automatically calculates the track geometry in longitudinal level and alignment, also integrating, for example, conversions of the measured track co-ordinates, fault analysis for investigating outliers and complex layout optimisation functions. Immediate processing of the measured track geometries is enabled by a direct interface with Technet's VERM-ESN track surveying and planning program used by DB (Fig 2).

One or more reference stations within 4 km supplies satellite-supported corrections to a kinematic measuring station on a rover (Fig 3). The calculator on the rover produces the co-ordinates of the actual track axis, and each co-ordinate is compared online with the target track geometry. This allows the production of any correction values required for the position, longitudinal level and cant.

Track surveying using EM-SAT

Bringing together the existing EM-SAT laser reference chord measuring system with the satellite-based SurVer technology, Plasser & Theurer developed a complete satellite-supported track surveying system in co-operation with Austrian Federal Railways and DB Netz.

The advantage here is that the laser chord takes over when reception from satellites is blocked by topographical features. All work is performed from secure workplaces, so there is no need for the usual costly staff protection measures required for conventional surveying.

Using the satellite measurements, the co-ordinates of the track relative to the reference points can be

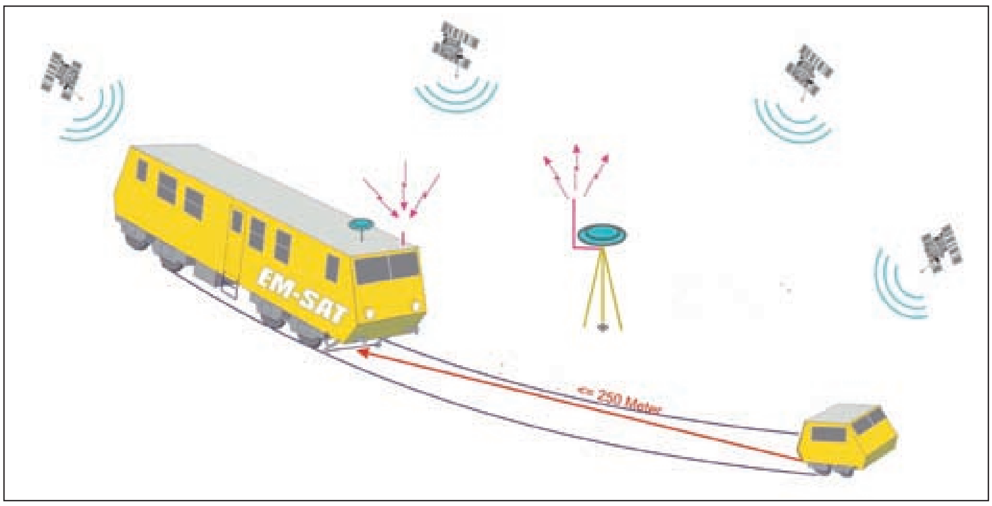

Fig 3. A graphical representation of the measuring process.

GNBAHN/PM runs on a pen-top calculator which is connected to the gauge-centred rolling surveying system carrier known as SurVer.

established with a geometric accuracy of around ±10 mm and a longitudinal level accuracy of around ±12 mm. The actual track geometry in terms of level and line is then established in relation to the laser reference chord. Differential satellite measurements are recorded continuously at the same time.

The satellite measurements are compared with the reference chord measurement to calculate the optimum corresponding values. Following this, or at the same time, it is possible to transform the end points of the laser chord into DB-Ref co-ordinates using a specially-developed transformation model (GN-Trans Geo++).

The laser reference chord measurement achieves track geometry accuracy of better than ±1 mm. Combined with the satellite measurements, the position of the chord can be exported as DB-Ref co-ordinates with a high degree of accuracy (Fig 4). In this way, lifting and lining correction values for the tamping machine can be established by comparing the absolute target co-ordinates with the measured ones.

Working with the EM-SAT

The satellite reference antenna is positioned on the roof of the main machine. But as the vehicle body alters its position in relation to the track (both in crossfall and lateral position), the deviations have to be measured and the position of the satellite reference antenna is corrected mathematically.

The satellite receiver calculating the absolute co-ordinates is located in the main cabin. This is linked via a radio data transmission unit to the satellite receiver standing at the reference point. The co-ordinates are calculated in real time and displayed on a separate monitor, so that the driver can check the system is functioning.

Measuring the compensation values must be performed with the highest accuracy, and a special compensation laser scanner was developed to ensure this (Fig 5).

In preparation for a survey run, the EM-SAT is positioned at the beginning of the section, and the laser front trolley is lowered onto the track and activated. The satellite and data transmission units are set up at the satellite reference point. For longer measuring runs it is sometimes advisable to set up a second reference point as well.

Measurements are then taken in a cyclic sequence:

- the satellite trolley moves forward as far as reception conditions permit (up to 380 m) — this is not dependent on the geodetic track points;
- the laser beam is aimed at the X-Y laser receiver camera of the main vehicle;
- EM-SAT performs a measuring run towards the satellite trolley;
- correction values for the measured reference chord are calculated and displayed in a graphical form;
- the satellite trolley moves forward again to the next measuring point.

Whereas the measuring output using geodetic track points was no more than 2 500 m/h at best, this can be raised by up to 15% because the measuring length is no longer dependent on the location of these points.

Evaluation of the calculated lifting and displacement values and the transmission of the data to the tamping machines is still done in the same way as it was before.

Guidelines for application

So that track maintenance contractors could benefit from the introduction of satellite-supported track surveying, DB Netz needed to redefine the interfaces between various areas of work. This was reflected in changes to guidelines 883 and 885 on surveying with effect from January 1 2006, and changes to the permanent way guideline 824.0310 from January 1 2007.

For each renewal or maintenance project, the railway issues to the

A GPS reference station provides the connection to SurVer.

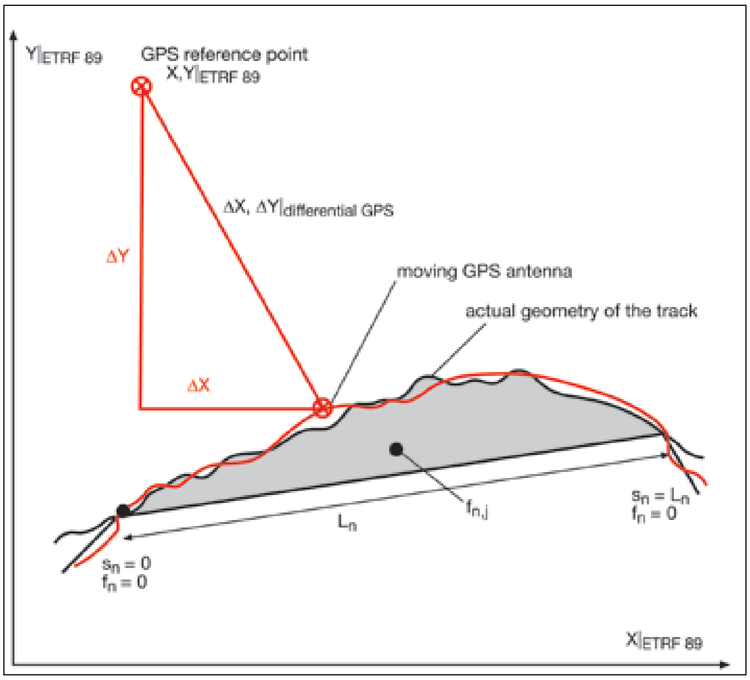

Fig 4. Satellite-supported measurements establish the precise track geometry.

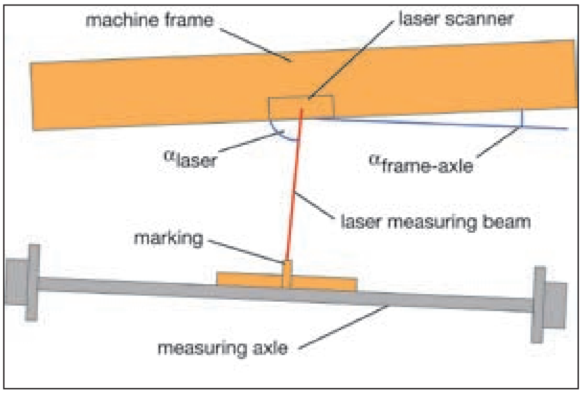

Fig 5. The functioning of the laser compensation scanner.

contractor the draft layout and the new layout, together with details of any renewal work, plus the details of location, track alignment, gradient and cant. For example:

3523_da0.PTS = kilometre line
3523_da0.PRR = rail head super-elevation
3523_da0.PTR = rail head curvature line
3523_da0.PGR = rail head gradient

In addition, the co-ordinates and documentation of the reference point(s) are provided.

Using these data, the contractor can calculate all the target versines required for alignment and gradient. If the EM-SAT is not available, measurements can be taken using SurVer. Lifting and displacement values are calculated using GNBAHN software and prepared for the tamping machine. For simple situations such as short worksites, the main points required in each case can be measured individually. Any necessary intermediate values can then be established by the machine's internal laser, complemented if necessary by manual measurements.

As a result of feedback with the first applications, the establishment of lifting and displacement values was added to the list of duties required for surveying work using DB-Ref with effect from 2007.

References

1. Marx L, Lahr B, Lichtberger B, and Wübbena G. Laserlangsehnenvermessung und Ermittlung von GPS-Absolutkoordinaten; (Surveying with laser reference chords and calculation of absolute GPS co-ordinates) Der Eisenbahningenieur 5.03
2. Marx L, Moßmann D and Kullmann, H.: Work procedures for maintenance of the permanent way of the DB Netz AG. 2006 **www.db-instructionbook.net**

A satellite rod antenna can be used to undertake measurements individually on smaller worksites or when EM-SAT is not available.