TRACK GEOMETRY CONDITION
THE BASIS OF AN EFFECTIVE MAINTENANCE STRATEGY

Coenraad ESVELD
Consultant
Esveld Consulting Services
Zaltbommel - The Netherlands

Ken DOUST
Director
Windana Research,
Centre-Sustainable Transport
Sydney - Australia

Introduction

Continental European railway operators by and large use a preventative approach to track maintenance. Emphasis on quality of track work and a thorough knowledge of the tracks service condition provides for a track which is predictable and reliable. Track geometry condition is a key aspect of this maintenance approach.

1. Modern railway track

Over the last 150 years railway track has progressively developed into a very refined transport technology. But for it to provide a very refined performance, the track needs to be viewed in terms of the dynamic conditions under which it is used. The passage of trains imparts not only static loads but also dynamic loads. The extent of this loading is dependent on characteristics of the track, the vehicles making up the train and how they all interact. Combined with these conditions are the climatic conditions producing temperature dependent changes in stress in the rails. It is an awareness of this dynamic environment which underpins the policies and strategies of these European railway operators. Minimizing the geometrical errors in the track at an early stage enables the passage of trains at the same speed, but without much of the dynamic load on the track and the train. Together with a track structure of uniform adequate strength, this approach provides a track of greater durability and less sensitivity to the passage of trains and climatic conditions.

Deterioration of the track is slowed, maintenance costs are less and the level of service for the passenger in the form of comfort and ease of movement about the train is higher. By providing positional stability, the temperature dependent changes in stress are controllable. The maintenance requirements are very much more predictable and the track very much more sustainable. A widening trend towards higher speeds in recent years is still further elevating the importance of track geometry condition in the strategic maintenance plans of these railways.

2. Measure of durability

The mechanism governing the phenomenon of track deterioration is rather complex. If a track is freshly tamped it is well-known that directly afterwards relatively large settlements occur. If every point of the track were to settle by the same amount no irregularities would develop. However, these settlements are often far from uniform due to inhomogeneities in support conditions, track structure and load distribution. This results in differential settlements which lead to the development of irregularities in the wavebands experienced by the rolling stock. To confine track deterioration it is of great importance to keep geometrical irregularities as small as possible, starting directly at the renewal, and to confine layer thickness variations during track renewal and ballast cleaning.

Deterioration of the geometry is identified as having three main causes: random settlement of the ballast, arising from the ballast itself, or from variations in the stiffness of the foundation, lack of straightness of the rails and variation in the dynamic loads along the track caused by vehicles. It was shown from calculations that the most significant dynamic loads could come from unsprung masses associated with wavelengths in the track of less than about 1 m.

In general, a high rate of deterioration in individual areas of a larger section can be linked to characteristics which are quite easy to detect:
- singular features (rail bridges, level crossings, etc);
- local geometry faults present from the start;
- sub-layers of inferior quality formation;
- welds of inferior quality.

With the examination of historical data described in [10] a very large amount of scatter was observed in the rate of deterioration. According to [9] for longitudinal level the maxima are about 10 mm/100 MGT, with current mean values from 1 to 2 mm/100 MGT, and for alignment the maxima are only about 2 mm/100 MGT. For this reason the longitudinal level indices, which vary more quickly, are preferred to the alignment indices when a decision has to be made on levelling/lining work.

With regard to the improvement of track quality by means of a maintenance operation, in many cases tamping machines reduce the track geometry to a relatively constant level, both for the longitudinal level and for alignment. Figure 1 presents the improvement in longitudinal level due to tamping over 4 test sections of 1.5 km on NS, where different methods of weld treatment were adopted using the STRAIT system and the GWM grinding train. Examination of standard deviations versus tonnage did not reveal markedly different behaviour over the four adjacent zones. They all deteriorate more or less linear at the same rate of about 1 mm standard deviation per 100 MGT, which corresponds approximately to the average deterioration rate on the NS network.

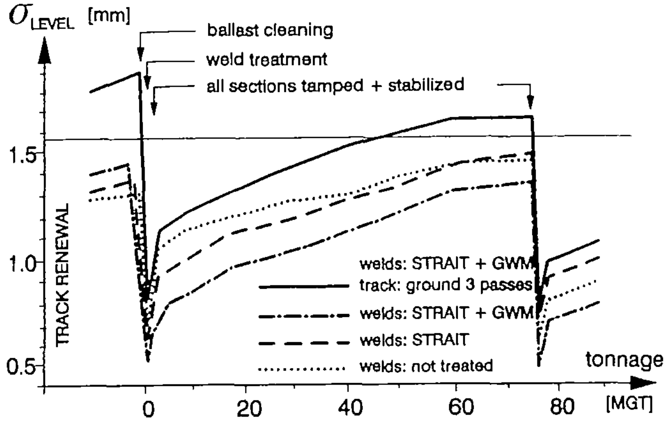

Fig 1: Average deterioration in level for 4 test sections of 1.5 km on NS

For properly monitoring track deterioration phenomena high precision measuring systems are required which should typically perform better than ± 0.1 mm standard deviation in the waveband 0 - 25 m [1].

3. Tools for maintaining track geometry

The European's in formulating maintenance strategies ensure that much emphasis is placed on achieving quality targets through the use of appropriate and technically correct techniques. Over the last 15 years a number of tools have developed to facilitate the control of track geometry condition in line with this emphasis.

Track evaluation vehicles came on the scene in the mid 1970's enabling large quantities of quantitative data on track geometry condition to be periodically gathered very quickly. This data has become the major input for decision making. With such large quantities of data becoming available, came the need for tools to enable analysis and information management. These tools enabled more effective maintenance programmes to be formulated for each of the remedial techniques. Track geometry condition maintenance programmes encompass a wide range of remedial techniques. Short wavelength errors such as corrugations require removal by grinding of the rails. Longer wavelength errors require repositioning of the complete track panel and repacking of its ballast support.

Localized dips at rail welds require the rails to be bent straight and the track panel to be repacked. Other errors in the geometry require a more extensive approach with renewal of the tracks formation, ballast and drainage. Tools have been developing for all of these techniques, to improve the quality of the geometry condition produced. Most have involved the application of microprocessors and electronic control technology. Netherlands Railways have been at the forefront in the development of these tools. Recently, this has enabled a new generation of track evaluation and analysis systems to become available.

3.1 Advanced Tools for Evaluating Track Geometry Condition

In modern track quality control accurate recording systems play a vital role. Railway engineers are well aware that high quality standards will pay off due to a reduction of dynamic forces and, as a result of that, lower deterioration rates, consequently leading to less maintenance. From this perspective it is essential to build and maintain tracks to tight standards, for which it is inevitable to use high precision measuring equipment, both at maintenance and inspection.

When dealing with track quality it is not necessarily geometry which is the decisive factor. From a physical point of view vehicle reactions due to geometry seem more appropriate. This requires to consider train forces as the sum of static and dynamic components, passenger comfort related to car body accelerations, as well as equivalent conicity and rolling line offset associated with vehicle dynamics. But also dynamic impacts from defected wheels should be considered as these may contribute significantly to damage and deterioration of the track structure.

Track recording systems

A survey of the geometry, adapted to the above maintenance processes via the indicated wavebands, is presented in figure 2.

λ	PHENOMENON	MONITORING
1 - 30 cm	*corrugations*	*axle box acc*
1 - 100 cm	*poor welds* *poor wheels*	*axle box acc* *rail accelerations*
2 - 3 m	*rolling defects*	*axle box acc/displ*
3 - 25 m	*medium waves*	*conventional*
25 - v/f m	*long waves*	*stabilized platform*
70 - ∞ m	*design geometry*	*quasi static*

Fig 2: Relevant wavebands for track quality assessment

Most of the modern track recording cars produce this, or part of this information in wavebands of similar dimensions. As described in reference [8] most commonly used measuring systems on track recording cars can be summarized as follows:

- axle box acceleration systems to monitor corrugations and poor welds. Application is possible at high speed. The main advantage is that the wheel response is measured directly [3];

- rail profile measurement systems based on optical techniques [5]. These data provide additional information in the decision making process for rail profile grinding, aiming at restoring a suitable profile from the point of view of curving and contact stresses. Also track gauge and lateral rail wear can be monitored and, if the accuracy is sufficient, parameters like equivalent conicity and rolling line off-set for accommodating vehicle dynamics studies.

- track geometry recording via a chord off-set system. This conventional approach has two major drawbacks: the transfer function between measured and actual geometry, as shown in figure 3, is not uniform, which causes distortion of the measured signals, and maintenance costs of the mechanical transducing system are relatively high;

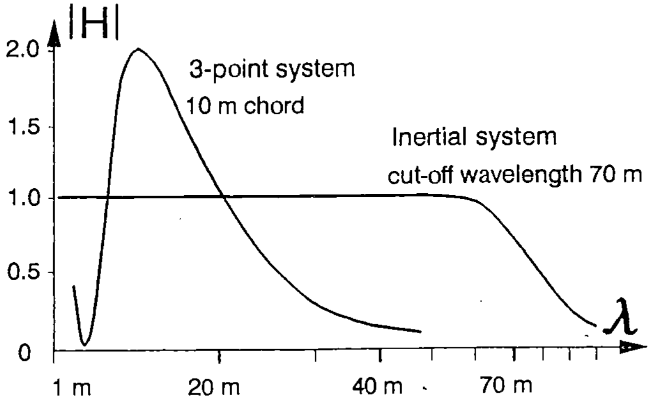

Fig 3: Transfer function 3-point system and inertial system

- track geometry recording via an inertial system, which has not the drawbacks of a chord system and, in addition, is able to record much longer waves, especially important for high speed tracks;

- vehicle response analysis in real time based on track geometry, measured independently of speed, from which the relevant vehicle reactions are calculated via transfer functions. Fundamental criteria concerning safety, such as the derailment criterion based on the Y/Q ratio and the Prud'homme criterion for lateral track resistance, are expressed in terms of forces and can be applied in this way [2]. This type of systems is now being operated in Holland [1] and Germany;

Wheel monitoring

To protect track components, especially concrete sleepers, against dynamic impact loads from poor wheels the exposure source itself should be considered first of all. High frequency wheel load components due to damaged wheels can be significantly higher than static loads. By detecting these wheels in an early stage via wheel flat detectors, the track engineer can - to some extent - protect his rails and sleepers. A well known principle of monitoring high impact loads is measuring vertical rail acceleration, as for instance adopted in the system described in [4].

Data analysis

In a track geometry signal random fluctuations are well monitored by a standard deviation, whereas local peaks can be represented by exceedences. Furthermore a dynamic part and a quasi static part may be distinguished in which the dynamic portion is normally representing a deviation which should be corrected and the quasi static component a deviation associated with design geometry such as super elevation and curvature in curves and transitions.

For assessment purposes the total range of relevant wavelengths is normally split up into a number of wavebands, as for instance shown in figure 2, in accordance with the vehicle characteristics and the potential of maintenance machines to correct the track geometry. For each waveband standard deviations can be established to be used as target value and as limit value, which are normally determined for relatively short sections in the order of 200 m length.

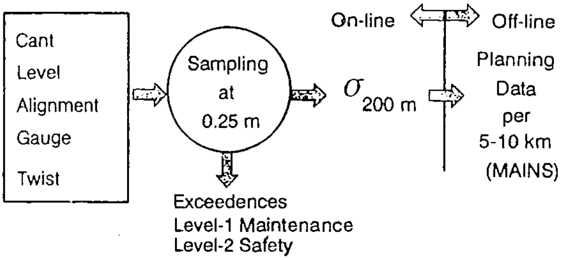

Fig 4: Digital analysis of track geometry.

For planning purposes the data should be further condensed to so called maintenance sections (MAINS), having a length of 5-10 km. Figure 4 summarizes the different steps in the digital analysis of track geometry. For further details please refer to [1].

An other important aspect to be considered is the behaviour of geometry as a function of time or tonnage borne. If the trends are known one can estimate future situations via extrapolation and also improvements due to maintenance, for instance tamping, can be estimated quantitatively.

3.2. Advanced Tools For Repairing Track Geometry.

A number of recent advances have also taken place in the tools for repairing track geometry condition. In the mid 1980's a very effective improvement was reached in the repair of dipped and stepped rails at welds. By an iterative process applied through a microprocessor, rails can be very accurately and controllably bent to correct errors prior to grinding.

Some railway administrations use the STRAIT system, which bends the weld iteratively to the required overlift of some tenths of a millimeter. The straightening device is part of a tamping machine as depicted in figure 5. The advantage is that immediately after the bending operation the sleepers ambient to the weld can be tamped, which is essential to achieve good durability. After straightening and

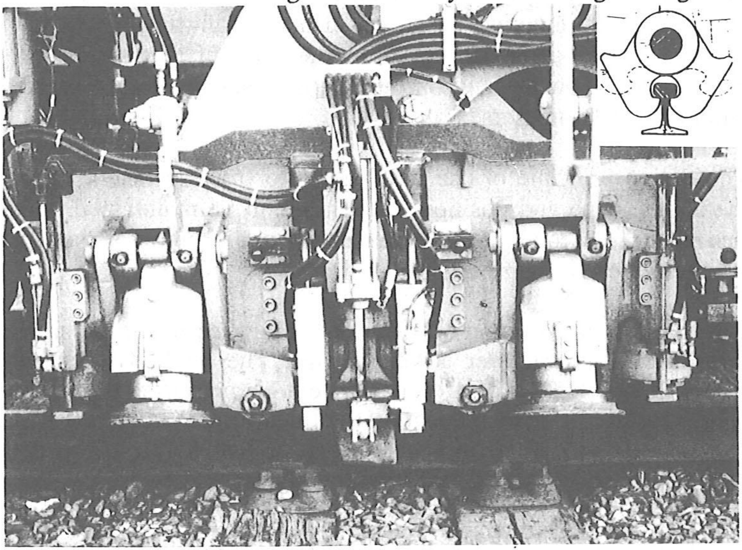

Fig 5: Straightening unit on tamper.

tamping the weld is ground to remove steps and local irregularities aiming at reducing the dynamic wheel rail forces. For further details please refer to [1].

Australia's State Rail Authority of NSW in the late 1980's commenced the development of a new generation of tools for improving control of the process used to reposition the track panel and repack the ballast support. The process is carried out mechanically using tamping machines which work on a face moving the flexible track panel sleeper by sleeper to its correct position. For these machines to achieve the correct result, continual referencing is required to a predetermined target position and shape. The late 1970's and 1980's saw microprocessor based tools develop in Europe for the purpose of providing this control. Building on the principle of these earlier systems the new generation of tools provide a greater degree of integration of both the software and hardware handling inputs to the tamping machine's measurement systems.

3.2.1. Database

Perhaps the most important cross linkage between the control systems is the database which forms the heart of this set of tools. Each of the control systems have been designed to take their data directly from the one data base ensuring uniformity in data structures.

The database automates the linkage between the survey office and the tamping machines, traditionally a problem in many railways. This data transfer is most simply carried out by floppy disc. A significant advance is that the quantity of data that can now be held on the tamping machine's database can be some many hundred's of kilometers.

The design principle of the database is to store sufficient information to enable the target shape and position of the track to be maintained. A logical addition to this principle is to store the actual shape and position of the track. These aspects are illustrated in figure 6.

All the data has a common frame of reference in the parameter specifying the location. This parameter is kilometrage. The methods of surveying track range from a purely localized reference system of measuring the track with overlapping chords to using a process relating the track to a countrywide survey grid network. In the latter case horizontal target shapes and positions are defined in terms of coordinates of key points called frame points and centres.

Frame points being the points on the target geometry where segments of geometry begin and end. For example, where a circular curve changes to a transition curve. Centres define the radius of the circular curve and are required in defining the shape of transition curves. Segments can be either straight, circular curves, transition curves or compound transition curves.

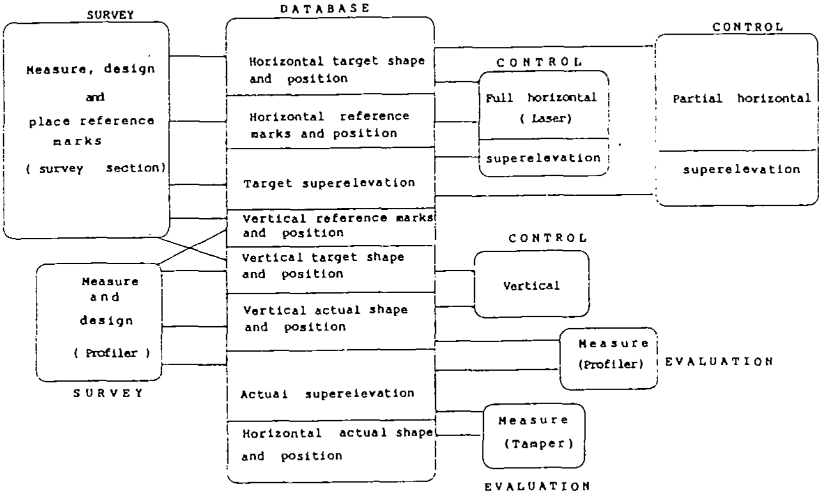

Fig 6: Data Base

3.2.2. Horizontal Control Systems

Two categories exist, full or partial horizontal control. Full control supplies both the inputs required by the tamping machine's measurement system. Full control is often known as design lining. The system developed in Australia was based on the principle of offset to chord, commonly used in Germany and the Netherlands (figure 7).

To be able to design line, the position of the lining chord of the tamping machine must be known. The target shape and position data is taken from the database as coordinates. The track is slewed until the distance (versine) between the track centerline and the lining point equals a calculated distance between the design centerline and the lining point.

The position of the lining chord is determined using a remote laser station set up at a distance in front of the tamping machine. This laser station consists of a standard surveyor's total station instrument normally used to measure distance and angles electronically. Attached to this instrument is a small infra-red laser and a remote microprocessor. The laser provides an external reference for the tamping machine, one of the two inputs required for full horizontal control.

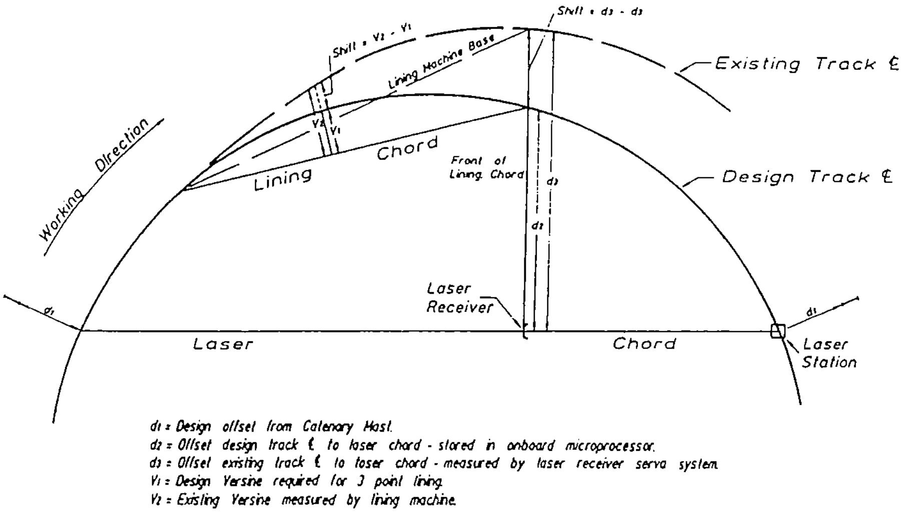

Fig 7: Principle of design lining

The laser beam is orientated by pointing to a light sensitive array on the front of the tamping machine lining chord. Position of the array is known at this stage by having already positioned the array radially adjacent to a reference mark.

Beginning its work cycle the machine travels towards the laser station, the array forming the sensor of a servo mechanism which keeps the array centered on the laser beam. The distance between the laser station and the array is continually measured by the total station instrument and relayed via the laser beam to the microprocessor on the tamping machine.

On the tamping machine the microprocessor continually calculates the co-ordinates of where the beam hits the array. By also monitoring the distance between the servoing array and the front of the lining chord by a linear transducer the microprocessor continually co-ordinates the front of the lining chord on the tamping machine. This coordinate is compared with the target position coordinate of the front of the lining chord known from the database. The principle of tamping assumes that the rear of the lining chord is on the target position at all times.

As the coordinates of both the actual and target positions of the lining chord are known, instead of physically moving the lining chord to the target position before the track is slewed, this system leaves the lining chord alone and calculates a mathematical adjustment to the target versine (figure 8). This replaces the hardware process of moving the chord with a software process.

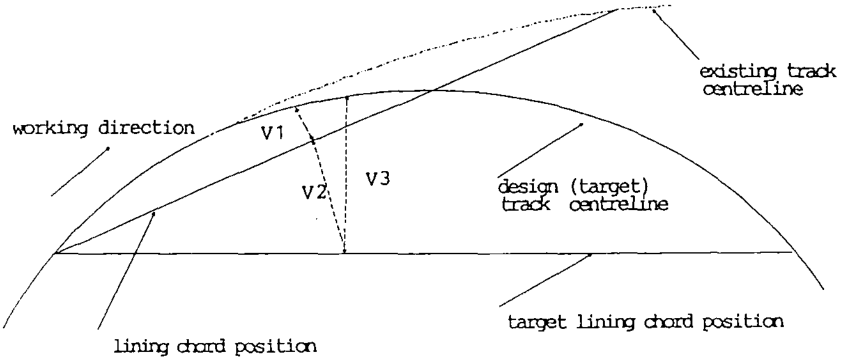

Fig 8: Adjustment to target versine

Target versine is the other input required for control of the tamping machine's horizontal positioning system and is itself derived from the data in the database knowing the distance between the machine's lining point and the laser station .

In the near future, a range of new measurement systems will further advance this system allowing more innovation in the way the tamping machine's lining chord position is coordinated. Partial horizontal control is a much simpler system in that the actual position of the lining chord on the tamping machine is assumed to be the same as its target position. This assumption is only useful when the track does not require long waves errors to be corrected and its position is within a close tolerance of its target position.

The process therefore does not require the complex measurement systems to coordinate the front of the lining chord. The only input needed is the target versine calculated by using the data from the database. An important feature of both horizontal control systems is the use of software calibration to eliminate an otherwise time consuming hardware calibration task.

3.2.3. Vertical Profiler

Building on the principle of a British Rail inclinometer tool for measuring rail profile and superelevation [7], the vertical profiler enhanced this design by adding a compact "lost-motion" mechanism [6]. This enabled a hand pushed, towed or self propelled unit to measure profile and superelevation at walking pace without the need to stop every sleeper.

Inclination over a base of known length enables the height of one end relative to the other to be calculated. This measurement principle with the inclinometer base in successive positions end to end along the track, enables the height of the track to be calculated. The profiler is linked to a microprocessor either on the tamping machine or on the profiler which records the height, superelevation and kilometrage of the track every second sleeper.

Data for a section to be tamped is analysed and an optimum vertical target shape and position calculated for the datum rail. The control data for the tamping machine can be calculated as the difference between target and actual vertical position of the track, known as the lift.

4. Conclusions

The combination of advanced tools for both evaluation and repair of track geometry condition provides a comprehensive approach to formulating and implementing strategies to maintain track geometry condition. These strategies are the basis of the high durability and level of service provided by the tracks in the worlds leading railways.

References

[1] Esveld C.: "Modern Railway Track", MRT-Productions, fax: +31 4180 16372, ISBN 90-800324-1-7.
[2] Hehenberger W.: "Fahrzeug-Fahrweg-Dynamik bei hohen Geschwindigkeiten aus der Sicht der Gleisinstandhaltung".
[3] High Tech Automation: "Digital Corrugation Measuring System". HTA internal report, 1990.
[4] Danneskiold-Samsoe U.: "Improving Track Quality by Means of Wheel Flat Detection", Caltronic internal report, July 1991.
[5] Roos J. and F.G.W. van Trigt: "Rail Profile and Gauge Measurement", TNO/TPD internal report, July 1991.
[6] Bingham S.: "Design and preliminary Testing of Railway Vertical Profile Measuring Unit", University Thesis, Page 32, University of Technology, Sydney, 1990.
[7] Waters J.: "The FROG measuring system", International Railway Journal, December 1984.
[8] Esveld C.: "Principles of Track Quality Recording and Assessment", Rail International/Schienen der Welt, January 1992.
[9] Esveld C., A. Jourain, G. Kaess and M.J. Shenton: "Historic data on Track Geometry in Relation to Maintenance", RAil Engineering International, 1988/2.
[10] ORE D 161 rp 1: "General conditions for the study of the evolution of track geometry based on historical information", Utrecht, April 1987.