Modern Railway Track
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Preface to the Digital Edition

After more than 10 years, and with the upcoming digital techniques, I considered it the right time to publish a digital version of this book. The present edition MRT-3 is just a digital copy of the original version of the Second edition, with all errata corrected and with some minor updates.

It is my intention to update the book in the next couple of years to the actual state of technology, with emphasis on weld treatment and slab track. But also contact mechanics, track components and the new EN standards will be treated. That digital version will be published as MRT-4.

It would be very much appreciated if the readers of this book will suggest any improvements or enhancements. Please don’t hesitate to contact me at coenraad@esveld.com. Actual information can be found on www.esved.com under the heading ‘Modern Railway Track’. At the heading ‘Downloads’ and then ‘Additional Downloads’ you can find pdf files of my lectures, conference presentations and a basic railway course in Dutch.

Autumn 2014,

Coenraad Esveld
10.4.4 Thermit welding ................................................................. 345
10.4.5 Cooling rates .................................................................................. 350
10.4.6 Improvement of weld geometry .......................................................... 352
10.4.7 Weld geometry standards ................................................................. 352
10.5 Rail failures ......................................................................................... 353
10.5.1 Defects in rail ends ........................................................................... 353
10.5.2 Defects away from rail ends ............................................................... 354
10.5.3 Weld and resurfacing defects .............................................................. 360
10.5.4 Rail defect statistics .......................................................................... 363
11 SWITCHES AND CROSSINGS ................................................................. 370
11.1 The standard turnout ............................................................................ 370
11.1.1 Set of switches .................................................................................. 371
11.1.2 Common crossing ............................................................................. 372
11.1.3 Closure rail ...................................................................................... 374
11.1.4 Rails and sleepers in turnouts .............................................................. 374
11.2 Geometry of the turnout ....................................................................... 374
11.3 High-speed turnouts .............................................................................. 375
11.3.1 General ............................................................................................ 375
11.4 Vehicle dynamic .................................................................................... 375
11.4.1 Examples of modern high-speed turnouts ............................................ 376
11.5 Notations used for switches and crossings .............................................. 377
11.6 Types of turnouts and crossings ............................................................ 377
11.7 Cross-overs ......................................................................................... 379
11.8 Switch calculation ............................................................................... 382
11.8.1 Relation between curve radius and crossing angle ......................... 382
11.8.2 Calculation of main dimensions ......................................................... 384
11.8.3 Geometrical design of switches and crossings ..................................... 385
11.9 Production, transport and laying of switches ........................................ 386
12 TRACK MAINTENANCE AND RENEWAL ............................................... 387
12.1 Introduction ......................................................................................... 387
12.2 General maintenance aspects ............................................................... 388
12.3 Spot maintenance of track geometry .................................................... 388
12.4 Rail grinding and reprofiling ................................................................. 390
12.4.1 Rail grinding machines .................................................................... 390
12.4.2 Rail reprofiling machines ................................................................. 392
The contact line should be kept at a constant tension for a good and continuous contact with the pantograph which is pushed against the wire by means of springs. The tension is obtained by weights or by means of gas cylinders at the end of the wire. Given the material of the wire (copper), the length of the wire (about 1500 m), and temperature fluctuations, length variations appear of about 50 cm. It is therefore of importance that the suspension points of the wires are able to move with the expanding and contracting wire.

Regarding this two catenary systems can be distinguished:

a. fixed suspension: for instance portal structures (Figure 1.2, left picture),

b. flexible suspension: for instance poles (Figure 1.2, right picture)

With a. the portals and carrying cables are fixed to each other. Because of this the carrying cables sag a little with warm weather and hence the contact wire as well. With b. the poles and carrying cables are fastened to each other flexibly. The cantilevers of the poles are movable and will change along with the carrying cables when temperature changes. The contact wire can now stay completely flat. The single pole structure is used with speeds of 140 km/h and higher. At lower speeds portal structures can be used.

Concerning metro systems the so-called third rail takes care of the supply of the current. This rail is installed next to the two rails carrying and guiding the train. Because of this no catenary system is necessary. This leads to a smaller clearance and therefore a smaller and cheaper tunnel construction is possible. When crossing over metro lines, the required height under the bridge can be lower. However, people should always be kept away from this third rail; the track should be inaccessible and without level crossings.
Tracks and switches are assets which will last for quite some years. The choice of a particular track system and the decision to use this system on certain lines, therefore, generally involves a decision which will hold good for 20 to 50 years. Consequently, such decisions must be taken with the future in mind, however difficult it may be to make a valid prediction. The only sure factor is that a certain degree of objectivity must be maintained vis-à-vis the present day situation, and not too much emphasis placed on random everyday events.

When choosing a track system, the above-mentioned requirements must all be given due consideration and it is clearly necessary to form some idea of the axle loads and maximum speeds to be expected in the decades to come. After this the situation regarding the various track components, such as rails, sleepers, fastenings, switches, and ballast should be examined so that the optimum track design is obtained.

1.6.2 Load-bearing function of the track

The purpose of track is to transfer train loads to the formation. Conventional track still in use consists of a discrete system made up of rails, sleepers, and ballastbed. Figure 1.8 shows a principle sketch with the main dimensions.

Load transfer works on the principle of stress reduction, which means layer by layer, as depicted schematically in Figure 1.9. The greatest stress occurs between wheel and rail and is in the order of 30 kN/cm² (= 300 MPa).
2 WHEEL-RAIL INTERFACE

2.1 Wheel-rail guidance

A rail vehicle basically consists of a body supported by secondary suspension on bogies in which the wheelsets are mounted and damped by means of primary suspension. Track guidance of the wheel is achieved in principle by making the following two provisions:

- The tires are conical instead of cylindrical which means that in straight track a centering force is exerted on the wheelset if there is slight lateral displacement. The centering effect promotes a better radial adjustment of the wheelset in curves. This leads to more rolling, less slipping and hence less wear.
- The tires have flanges on the inside of the track to prevent derailment. In case of more considerable lateral displacement both in curves and on switches, the lateral clearance between wheelset and track is often no longer sufficient to restrict lateral displacements adequately by means of the restoring mechanism previously discussed. Should the wheel flange touch the rail head face, this can result in high lateral forces and wear.

2.2 Wheelset and track dimensions

Generally the track gauge is used as a distance measured between the two rails, more specifically the distance between the inside of the railheads measured 14 mm below the surface of the rail. By choosing 14 mm the measurement is less influenced by lipping or lateral wear on the rail head and by the radius $r = 13$ mm of the rail head face. On normal track the gauge is $1435^{+10/-3}$ mm with a maximum gradient of 1:300. For new track, however, NS apply the following standards:

- Mean gauge per 200 m: $1435^{+3/-1}$ mm
- Standard deviation within a 200 m section less than 1 mm.

Figure 2.1: Wheelset and track dimensions for straight normal gauge track
Here \( r_1 - r_2 \) is the instantaneous difference in rolling radius of the wheel treads; generally speaking this is a non-linear function of the lateral displacement \( y \) of the wheelset with respect to the central position. The difference between conical and worn profiles is given in Figure 2.7. To enable numerical comparisons \( \gamma_e \) is at a certain lateral displacement \( y = \bar{y} \).

With a conical profile the conicity is constant and (2.8) becomes (see also):

\[
\gamma_e = \frac{1}{2} \frac{\Delta r}{y} = \frac{1}{2} \frac{(r + \gamma y) - (r - \gamma y)}{y} = \gamma \quad (2.9)
\]

In the next paragraph the effects resulting from progressive non-linear behavior of the effective conicity and its influence on the running stability of vehicles and rail wear are dealt with in greater detail.

### 2.6 Worn wheel profiles

A perfectly conical wheel profile is unstable as far as its shape is concerned, but will take on a shape that is stable as the effect of wear. In addition, conical profiles have the disadvantage that a substantial lateral movement will, because of the two-point contact, lead directly to an impact. If the profile of the rail and wheel tire at the point of contact is assumed to be circular, it can be deduced from Figure 2.8 that in the case of lateral displacement \( y \) of the wheelset with respect to the track, the contact point on the rail will over a distance translate to:

\[
\Delta s = \frac{\rho_w - \rho_r}{\rho_w - \rho_r} y \quad (2.10)
\]

Moreover, if the value of \( y \) is small compared to the radii, the following relationship holds true:

\[
\Delta r = \tan \phi \frac{\rho_w - \rho_r}{\rho_w - \rho_r} 2y = \gamma_e 2y \quad (2.11)
\]
give a stable equilibrium, but will instead induce a highly frequent jumping to and fro between two points on the curve.

2.7.6 Spin

Apart from slip in the longitudinal and lateral direction a third quantity also exists: the so-called spin which also participates in transmitting the friction force. Spin or rotational slip arises if the small contact area between wheel and rail is not parallel to the rotation axis of the wheelset. The rotation vector of the wheelset can then be decomposed in a component parallel to the contact area (this is pure rolling), and a component perpendicular to it, which is the rotational slip or spin as indicated in Figure 2.23.

The spin is defined as:

$$\phi = \frac{\omega \sin \gamma}{v} = \frac{\sin \gamma}{r}$$  \hspace{1cm} (2. 16)

It should be noted that the spin $\phi$ has a dimension $[1/m]$.

When spin takes place, the relative movements between wheel and rail will also partly be taken up by elastic distortion and partly by slip. The result will be that in the contact area forces are generated with varying magnitude and direction, the resultant of which produce a force in the lateral direction. This can be clarified by means of Figure 2.24.

In this picture, which was used in numerical considerations about contact mechanics, the contact ellipse is divided into a grid of small elements. Each element shows the magnitude and direction of the slip regarding that element.
After adjustment, the rail is made stress free by means of heating before the compound is poured into the groove (Figure 9.52).

### 9.8.3 Experiences with embedded rail

Many pilot tracks of embedded rail have been applied over the last 30 years, 246 m paved-in as well as main-line track. Nearby Deurne (The Netherlands) in 1976, a pilot was constructed in heavily used track with speeds up to 160 km/h. The track existed of a series of 6 meters of prefabricated slabs containing the gullies supported underneath with old NP46 rails [201]. The experiences were qualified as positive. In 1994, the rails were renewed, but the wear of those rails was considerably less compared to the adjacent track.

Another large pilot concerned 3 km track nearby Best (The Netherlands) which came into operation in October 1999 and is currently being monitored.

The superstructure consists of a 42 cm thick slab with longitudinal reinforcement providing the slab with a high flexural strength. The slab lies on top of a concrete road bed and stabilized subsoil. The cross section of this track structure is shown in Figure 9.48, while the construction process of this test track is illustrated in Figure 9.49 up to and including Figure 9.54.

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**Figure 9.48: Cross section of the embedded rail superstructure near Best**

---

**Figure 9.49: Installing of the rails**

**Figure 9.50: Positioning of the rails by means of wedges**
A water-cooled oxygen lance is lowered into the furnace and high-purity dry oxygen is blown onto the metal at very great speed. The oxygen combines with carbon and other unwanted elements, thus eliminating these impurities from the molten charge. The carbon is blown down to less than 0.1%. During the "blow" lime is added as a flux to help carry off the oxidized impurities as a floating layer of slag.

The positioning of the lances, the determination of the volume of oxygen to be injected, the additions to be made and
11 SWITCHES AND CROSSINGS

11.1 The standard turnout

Turnouts are used to divide a track into two, sometimes three tracks. The purpose of crossings is to allow two tracks to intersect at the same level. If a complete train is to pass from one track to another while moving and without being subdivided, turnouts are essential in the absence of turntables or traversers.

It must be possible to run through switches and crossings in both directions. A normal or single turnout, as shown in Figure 11.1, allows movement of traffic in a straight direction on the through track or in a divergent direction. A picture of the right-hand turnout is given in Figure 11.2.

The turnout consists of three major parts:
- Set of switches (switch blades);
- Common crossing;
- Closure rail.

These parts will be discussed separately below.
Figure 12.61: Formation rehabilitation machine AHM 800 R

Figure 12.62: Example of tracks after formation rehabilitation with geotextile
16.10.4 Quasi-static signals

In addition to the dynamic signals, quasi-static signals are produced for cant, curvature, and gauge. The measuring principles are presented schematically in Figure 16.84. Problems due to drift and lack of initial conditions mean that the quasi-static cant is not determined by integration of the rate gyro signal, but by making use of the lateral car body acceleration, curvature, and recording speed as indicated in Figure 16.84.

<table>
<thead>
<tr>
<th>CANT</th>
<th>CURVATURE</th>
<th>GAUGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\gamma} = K v^2 - g \phi_B$</td>
<td>$K = \frac{1}{R} = \frac{\theta}{L}$</td>
<td>$Y_g = Y_L + Y_R + 1435 \text{ mm}$</td>
</tr>
<tr>
<td>$\phi = \phi_B - \Delta \phi$</td>
<td>$\theta = \theta_1 + \theta_2$</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 16.84: Recording principle for BMS-1 quasi-static signals](image)

Two other transducers are, in addition to the two linear displacement transducers between car body and bogie frame in the measuring bogie, installed in the second bogie to record curvature according to the principle sketched in Figure 16.84. The quasi-static gauge is directly derived from the line-scan camera signals.

All three quasi-static signals are low-pass filtered with a 3rd-order Bessel filter. The phase relationship is linear and causes a distance delay of 27.5 m. As the curvature recorded in fact corresponds to the car center, the delay of the signal in relation to the measuring bogie amounts to 35 m or 20 m for forwards and backwards running respectively. With the introduction of VRA this delay can be corrected.

16.10.5 Signal combination for determining track parameters

The track parameters produced by the former BMS system of NS are derived from a combination of signals provided by 16 transducers, i.e. 1 rate gyro, 2 accelerometers, 10 LVDTs, 2 line-scan cameras, and 1 tachometer. The location of the various transducers is indicated in Figure 16.85. The track parameters are derived from the following expressions:

Level:

$$Z_r = \int \ddot{z} - \frac{z_1 + z_2}{2} + \Delta z$$  \hspace{1cm} (16.6)
16.18 Weld geometry standards

**Force geometry relationship**

Dynamic components of the wheel rail contact force have a significant impact on track deterioration and should therefore be kept as low as possible. Weld geometry plays an important role as a main contributor to high-frequency loads. At TU Delft this aspect was given high priority in the early beginning of the 21st century, with a study aiming at developing a theory, with associating algorithm, to describe dynamic component of the vertical wheel rail contact force. The algorithm should be such that it could be implemented in a PDA, or handheld computer, fast enough to make real-time calculations within seconds.

The existing ways of weld geometry assessment were based on considering measured versines which were then tested against maximum allowable values. From the theory developed at TU Delft it became apparent that the versine approach was not correct for representing forces, but that instead the inclination of the geometry, in fact the first derivative of the measured versines, should be taken. All the filtering and analyzes are made in a PDA and presented to the user in a normalized way via so-called quality indices (QI). The theory behind this concept was documented in various publications, amongst others [309, 310]. The paper ‘Force-based Assessment of Weld Geometry [309] received the Best Paper Award for Infrastructure at the WCRR in Montreal, Canada, June 2006.

The vertical wheel rail contact force is approximately proportional to the square of the speed. In this way the standards are speed dependent. Furthermore the contact force is linearly related to the inclination (first derivative dy/dx of the geometry).

\[
F_{\text{dyn}} = \text{Constant} \times v^2 \times \frac{dy}{dx} \tag{16.43}
\]

The inclination is determined from the versines measured with the RAILPROF on a base of 1 m, sampled at an interval of 5 mm. During data processing the samples are averaged (low-pass