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Some Remarks on Modern Track Geometry Maintenance

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A B S T R A C T

A short survey on modern track maintenance methods is given, concentrating on the developments in recent years. The ongoing refinement of the machinery should be shown as the influence of IT-solutions should. On top the economic view to the track infrastructure is briefly demonstrated. Further developments in track hardware solutions must respect the obtained high level of track work mechanization. However, with respect to presentation time some other ongoing developments unfortunately are not discussed. Prominent amongst those are: the advent of high grade rail steels like heat-treated perlitic steels, the experiments with bainitic steels and the introduction of hydraulically driven turnouts with special high-speed-prone rail geometry or the latest machine sets for general subgrade rehabilitation.

1. Introduction

Over the last decades a gradual development of track to become a fully engineered structure was seen, with theories describing the complicated interaction between the main substructures rail, sleepers, ballast and subgrade and extended experimentation as a side-effect of a general modernization of Railways to higher capacity, travelling speed and comfort.

2. Track Recording

Track geometry recording by fast travelling vehicles is the base for net wide track condition evaluation, resulting in decisions for necessary maintenance [1]. European legislation has produced standards, which now are in power in all European states in the same way. The definition of three levels of care, namely;

1. values of “attention”
2. values of “urgent action”
3. values of “immediate action”

deserves the attention of railways outside Europe as well. The respective figures are set in accordance with the track category, the permitted speed and the track importance. The offsets are recorded in “absolute” deviations to overcome the tricky problem of recalculating relative measurements like offsets from versions. Such track recorders are on the market as self-propelled vehicles (up to 160 km/h) and recording coaches without traction (up to 250 km/h and more). They work together with “data-store-facilities”, mostly in a central office, which allows comparisons between various sections, but also an evaluation of the geometry states over time. In many countries also a general “quality-index” is derived for a general outlook. Unfortunately, it was not possible (until now) to agree on a method of deriving a general common quality-index, used in the same way in all Europe.

3. Pre-measurement

For preparation of track realignment a pre-measuring device was developed, which

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constitutes the actual geometry. Sent to central calculation the correction values are re-transferred and used by the tamping machines straight away.

4. Describing Track Geometry

Intensive thoughts were given to the mechanisms of track geometry deterioration and respective research was carried out. By observation a law of track quality deterioration was found and mathematically formulated. It is used today also in economic considerations and decision making.

Observation of track geometry development indicated that the change in track quality over time (or running load) is proportional to the quality itself. This led to the formulation of an equation describing the law of deterioration. (Note: Q is taken as negative, as is always lacking against ideal, Equations 1 and 2, Figure 1)

$$\frac{dQ}{dt} = cQ \qquad (1)$$

The solution can easily be found by:

$$Q = Q_0 e^{bt} \qquad (2)$$

This indicates that:

- Track Quality depends (at least) from two parameters:
  - The Initial Track Quality Q_0 and
  - The degradation factor b
- Track geometry is not a state, but a development
- To describe track geometry a function is needed
- This means that a number of track recordings are necessary to defining this function. Or: One result says nothing!
- The perfect track (Q_0 = 0) is not attainable
- The degradation factor b is a function of local circumstances, track design and loading characteristic. It will differ throughout a railway network.

On basis of these considerations money effective maintenance policies have been developed, looking not only to these results, but also the experiences of staff in practical maintenance responsibility. These seemingly "academic" approaches also have a very practical result, which directly effects the discussion on re-organizing railways, as is a major political project in Europe within the European Institutions, emerging a long list of new legislation valid in all EU-states.

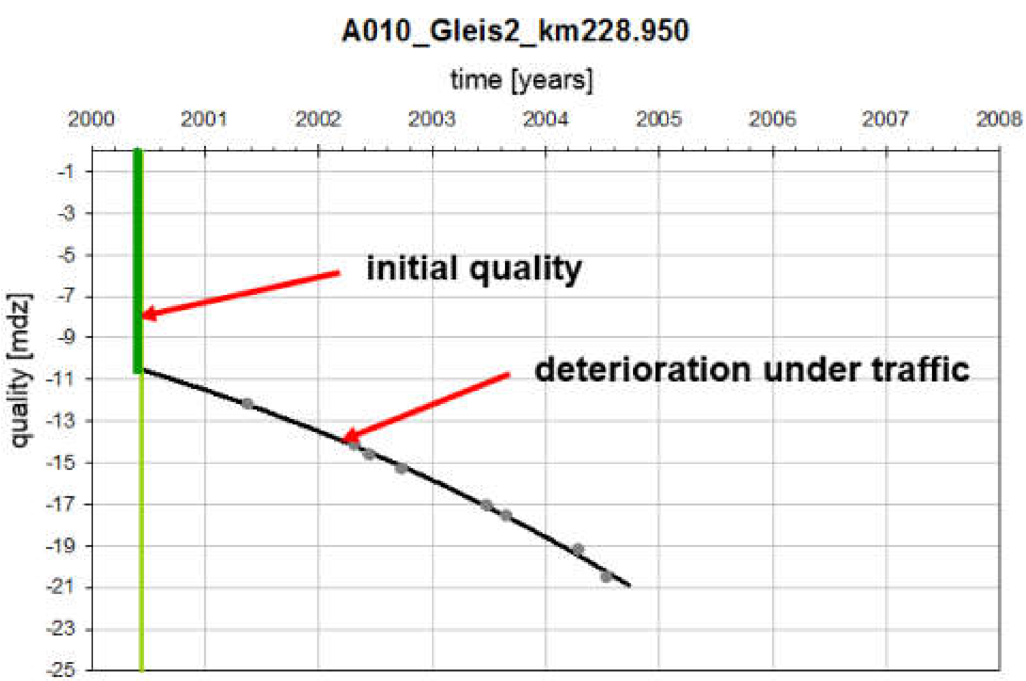

Figure 1. Track quality development over time

As running track quality depends from two parameters (Q_0 and b) the question is: which cares for what?

The initial track quality Q_0 is quality just at the start of train operations. Track laying is done by infrastructure administrations on the renewal budget. Running track maintenance is done by another part of the organization, with a different budget for maintenance. These people both are "responsible" for b, taking care for small maintenance, regular track reconditioning by repeated geometry improvement etc. up to heavy maintenance with ballast cleaners.

What, if the renewal organization saves money by producing a low Q_0 only? Then the maintainers have to invest more to keep track geometry to the standards. No doubt, an excellent Q_0 would strongly help to keeping a good b as well, if the subgrade and ballast conditions are favorable. A number of impressions are given later, when track quality always is shown by functions rather than figures.

5. Ballast and innovative Sleeper Designs

"The weakest element in track is ballast". This is the conclusion of many papers over the last decades [2,3]. Ballast is loaded via the sleepers and contact between concrete sleepers and ballast is an interesting issue. In fact a very limited contact was experimentally found and the benefit of an intermediate elastic layer recognized. The footing of concrete sleepers by elastic bottom pads ("USP" – under sleeper pads) is almost 100% standard with newly purchased concrete sleepers in Austria today, in other European countries the application is also growing. The advantage of such refinements is demonstrated by research and observation. Maintainability, however, does not only depend from machinery, but to a high extent from the used track material. Some examples demonstrate the influence of modern Maintenance Technology on the development of track components. Some new sleeper types are under test now for almost 15 years [4,5].

One idea of general interest is the German experiment with "wide sleepers" (Figure 2). Those are arranged in the standard distance of 60 cm, but are as wide to come to lay side-by-side with the next sleepers.

Figure 2. "Wide sleepers" (Germany, 1999)

Such a full plane contact is developed, which reduces ballast stress and discontinuities. A test section of 11 km length has been installed in Germany in 1999, not much was heard about results since. The major difficulty in installation was the creation of an original track geometry status by tamping. It is evident that normal tampers are not able to undertamp this type of track as there is no insertion space. As a matter of fact a special machine was used which provided tamping action from the outside, with wider tamping tines working ballast towards the track center. Careful observation confirmed the success. (In the meantime this special machine was taken out of production and scraped).

An old idea of the "genius of railways", Dr. Carlo Ghega, from 1854 (Figure 3) was taken as a base to create "frame-sleepers" [6]. A standard cross-sleeper-track is supplemented with a longitudinal beam, situated under the rails. As bends and changing cross-levels are necessary these longitudinal beams are not stiff, but comprise of short sections. Two sleepers are arranged to form a "frame". The available literature demonstrate the emerging design. While in the beginning also pre-stressing was considered feasible by two strands only, with experimental testing showed that this expectation was too optimistic. Nevertheless, the existing test sections (some since 1999) show excellent durability of track geometry until today, even if cracks in the concrete body reduce full satisfaction. 180° curves within the concrete body the next step was straight pre-tensioning with straight strands in perpendicular arrangement.

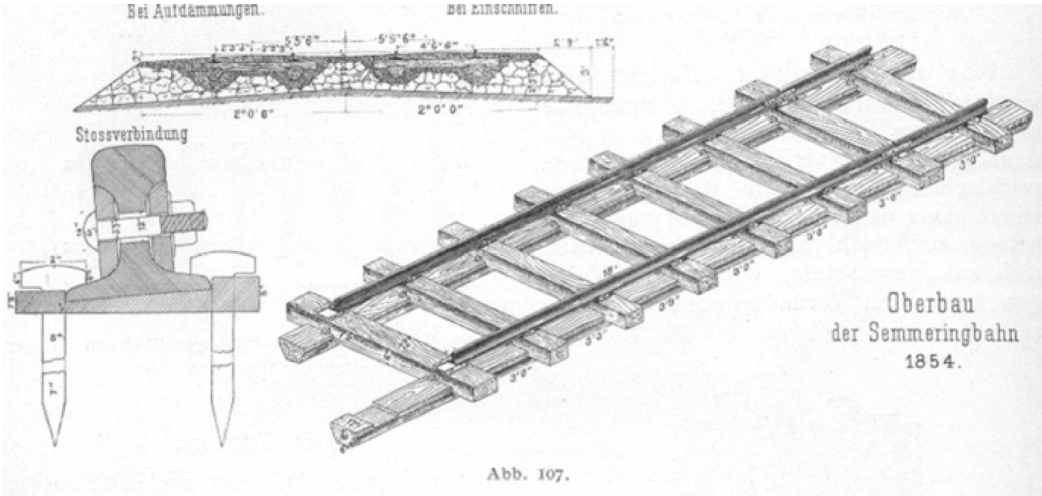

Figure 3. Historic track design (Ghega, 1854)

Those frame-sleepers fulfilled the expectations, but came out to be extraordinary expensive due to this pre-stressing in two perpendicular directions.

In 2006 the American Railroad Company “Union Pacific” called for ideas to significantly reducing the track maintenance efforts. To answer this call the original idea of the fame-sleeper was realized: cross elements in a distance of 60 cm, with incorporated longitudinal elements. Due to the expected axle load of 35 (metric) tons to design was somewhat more massive and the reinforcement stronger. To accommodate delivery of the test sleepers to the US it was decided to separate the frames into two “half-frames”, one cross sleeper body with reinforced concrete additions under the rail in either side. These “half-frames” became known as “dog-bones” (Figure 4).

The most prominent test installation is presently situated at the test center TTCI in Pueblo, Co, USA, where an automatic Heavy Haul train circles a loop with a manifold of test components. Under 35 metric ton axle loads the innovative track so far underwent accumulated about 800 mio (metric) tons train load without a need for geometry repair. The ballast is maintained in excellent order as a result of the sleeper shape, the elastic sleeper bottom and the high lateral resistance. The excellent behavior of the test section is highlighted by the annual report of TTCI, Pueblo, Colorado, every year again since. The last one, from December 2014, underlines the massive overall improvements.

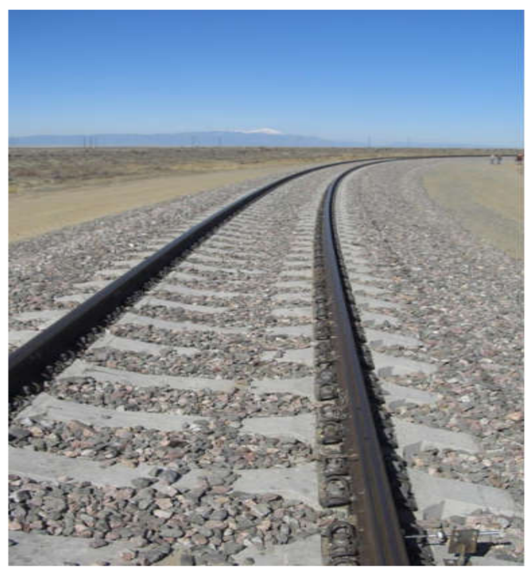

Figure 4. “Half-frame-sleeper track” (TTCI, 2009)

However, economic considerations dictate European decision making. And innovations, as much money saving they would allow in future, are always somewhat more expensive at inception. So, an even less expensive realization of the basic idea of frame-type track was suggested. It consists of a regular cross-sleeper track, supplemented by blocs under the rails bridging the gap between the sleepers.

Figure 5. "Frames by added blocks" (TU Graz, 2011)

Those are only attached to the rails (Figure 5). The advantages are clear: The ballast "feels" of a full frame-sleeper, the cross-sleeper is cheap as it is mass-produced, installation is easy, particularly if track is laid or re-laid, and there is one more option: Track can be individually strengthened at problematic sections like weak subgrade, bridge approaches or road crossings etc. The test section, laid in late 2011, so far shows the expected excellent behavior.

6. Modern Mechanized Track Maintenance

Regular Track Geometry Maintenance is done by highly sophisticated machinery, designed to carry out necessary operations with little manpower and least cost in ballasted tracks and turnouts as well. High hourly output is a must with regard to the ever reducing train intervals as a result of the growing train numbers throughout Europe. Based on information gained with track recording coaches work plans keep maintenance works within budget and labor resources.

6.1. On-board computer

The key feature of modern track tamping machines doubtlessly is the central computing unit, which calculates all necessary adjustments values for track geometry improvement and simultaneously adjusts the controls to the needs. This way the adjustments are executed at time, in the correct manner and under observation of some cross-influences, which were phased out in the old days like overshooting track levels in very tight, super elevated track curves. Beside these advantages also working speed was increased as geometry correction systems do not need a reduction of work rhythm any more. The inputs into the board computer can be done beforehand under more quiet conditions and only need synchronization with the actual track at characteristic track point (for instance "begin of transition"). Precondition, however, is the knowledge of correct track geometry. This also is precondition for the use of the lining system with three referencing points only. As the central computer calculates the correct versions on the basis of the actual machine dimensions a smoothing method ("4- point-lining") is not necessary any more. On top these 3-point-lining systems are much more "direct" and thus more effective in re-installing the correct, pre-defined track geometry.

7. Track Alignment to Outside References (Fixed Points)

To best compromise excellent track geometry with thermal stress in curved continuously welded rails the method of aligning track in accordance with outside monuments became almost standard throughout Europe. The necessary fixed points are now placed at the catenary masts in corresponding height at about track level (Figure 6). Together with data-banks, holding the respective surveying data, this infrastructure base is used by the track services for geometry control and as a reference for track works as well. Modern IT-solutions allow access to these data directly from the track site. By maintaining track geometry in small tolerances the stress state of the rails is well under control.

8. Over Lifting

Track engineers since almost two centuries are busy to maintain track to the needs. Over the years they came to learn that track behaves like a human, with resistances and good-will – and with a memory! In track we experience the re-appearance of track errors which just were corrected. This is a result of the lift-Settlement relation, which explains that every lift is followed by a settlement under running traffic.

In the frame of an ORE project this function was researched at the former Derby Test Centre in the UK. There is an almost linear relation over most of the lift range. Deviations are seen at small and very small lifts.

Analyses of old methods of track geometry correction teach that always some “over lifting” was done, with hand-tamping, shovel-packing and even stone-blowing. The idea is clearly: Over lifted track will be smoothed by running traffic and thus track geometry be improved rather than immediately deteriorated. This gave rise to look into a similar option with tamping machines. Respective experiments with “over-lifting” demonstrate in fact an option to extend tamping intervals. The low sections in track geometry are proportionally lifted beyond the 0-level-target to allow for more settlement. Train operation will smooth the uneven vertical geometry. The result is a longer durability of the re-established track geometry. The experiments so far are promising and together with Austrian Railways ÖBB a project has been started to further develop this idea to production maturity. However, one critical issue should be noted: Over lifting does not result in an even, level track geometry, but in phase-correct, reversed unevenness of the worked track. While today an eye-look along the rails allows to evaluate a track geometry as “perfect” this would not be the case with “over-lifting”. No doubt, that this would cause intensive discussions on site!

9. Tamping Frequency

Research over years confirmed the tamping frequency of 32-35 Hz as the “optimal” one, giving good ballast stability at target lift. At the same time respective research came out with recommendations regarding the tamping tine frequency at the insertion phase, when the tines dig into the ballast. Tests with varying frequencies within a tamping cycle have been successful and will possibly be standard in some future.

Tamping speed has been pushed up over the years, starting from single-sleeper-tampers in 1945 to 4-sleepertampers in 2005. Respective working rates went up from 120m/h to almost 2400m/h, the 20-fold! The tamping machine sets the pace for the work-speed of the whole group of machines, which form the “track-maintenance train”, consisting of two, in many case three machines: the tamping, levelling- and lining-machine, a ballast regulator and the “Dynamic Track Stabilizer (DTS)”.

Figure 6. “Fixed point” for track reference

10. Dynamic Track Stabilization

The “Dynamic Track Stabilizer (DTS)” (Figure 7) was developed on demand of the French Railways SNCF in the mid-1970´s, which feared a risk of instability after tamping conventional ballast track, which they decided to install at the (then) new High Speed line Paris-Lyon. The goal was to stabilize the disturbed track structure to stand higher lateral forces, which occur at (very) high speeds, avoiding any immediate track geometry deterioration.

The prototype was used to establish the parameters for a reliable ballast compaction. Tests were done in many European test institutions and countries. They all showed remarkable increase of lateral resistances, which was elevated from 50% only after tamping to about 85% after additional stabilization. This proved satisfactory to operate trains with full speed after tamping works, while before that rather sophisticated sequences of slow orders were established to cater with the reduced track stability.

Figure 7. "Dynamic Track Stabilizer (DTS)"

It is but not only lateral resistance which is influenced by the DTS, it is also the vertical durability which matters. To make a long story short: the DTS is also stretching the time interval between tamping operations by its general track compaction and distressing action. Mr. Brown, former Chief Engineer of the American Railroad "Union Pacific (UP)" once noted: "Before the DTS we had to tamp every 3 years, after DTS every 4 years!"

In High-Speed operation the problem of flying stones is observed. Ballast particles are pulled out of the ballast, accelerated by the air-stream under the carriages and thrown away in an unpredictable manner. Flying stones are an obvious problem. This phenomenon appears at speed beyond 180 to 200 km/h and becomes the more serious the higher the speed. It is seen primarily at freshly tamped track. Cleaning the sleeper tops and lowering the ballast surface by some 4 cm between the sleepers has proven to be an adequate measure.

The use of the DTS, however, compacts the ballast surface to an extent that ballast stones are well held in place.

Observations and experiments of ADIF, the Spanish rail infrastructure manager, concluded that first of all ballast stones are prone to "flying", which before laid loosely on the top of the (concrete) sleepers. The approaching train makes them jumping and loosing contact with the bottom and offer a situation, which makes "flying" easy.

This in reverse also means that too much ballast in the track should also be prevented as too much ballast is.

Two more effects of the DTS are the combination of equalizing rail stress together with a "full-body compaction" of the entire track structure. It is not a particular area of ballast, which is consolidated by vibration, it is the track including the ballast in full width. This consolidation is seen by the immediate settlement while the machine is working. It is evident that the working speed must be kept constant to achieve uniform compaction. The working effect is almost insensitive against working speed: with 800 m/h the same results are found as with 3200 m/h, more than the highest working rates of tamping machines. Tests with higher speeds have been carried out only - by mistake. 5 mph (8000m/h) did not give satisfactory results, but this never was the specification for this machine!

The DTS is a completion of track maintenance technology, which is now on the market for 40 years and still is under debate. The increased track stability unfortunately is not seen by eye nor experienced by touching. Where ever this technology was introduced an extension of tamping cycles was observed. Clearly, if this outcome is not transferred into new maintenance routines then nobody can expect an economic success. Every step forward in technology needs adaptation of the respective routines.

11. Economic Considerations

Evaluating track and track work in economic terms was developed over the last 15 years by the Institute of Railway Engineering and Transport Economy at the Graz Technical University. It is the intention to look after track not only from the technical, materialistic point, but to handle the price-tags., which are attached to every decision and action respectively. In this way a new, price-labelled railway is created. With the various established methods of economical academia new aspects are reached, which highly influence decision-making.

As one quick example the question is asked, whether it is more appropriate to keep track on poor subsoil as it is, only keeping geometry by frequent intervention in a safe state for train movements or invest in a major subsoil rehabilitation to improve the situation verbally "from the ground".

Figure 8 shows the way of calculation: The actions, known by experience (mostly by the staff on site!) are listed year by year in today-value money.

The two options from above are listed side-by-side and the differences are calculated for every year. The sums over the years give the "cash-value" (which is of minor interest here). The differences, however, are treated with various interest-rates as shown and summarized to a "cash-sum". The one "cash sum" which results in "zero" refers to a particular "Internal Rate of Return", and gives an immediate impression of the advantage of an intervention. The graph (Figure 9) displays the function over the interest-rate: At 0% the full "cash-value" is found, the function passes 0 at the "Internal Rate of Return", which (in this example) comes to 65%! This leads to amortization time of only 1 ½ years, when the investment is earned back! In this case a subsoil rehabilitation would be extremely economic.

year	technology I	technology II	difference Δ	Interest rates 5%	10%	15%	IRR
1990	laying LLT	laying LLT					
1991							
1992		LLT grinding					
1993	LLT						
1994		LLT grinding					
1995							
1996	LLT	grinding					
1997							
etc.	etc.	etc.					
				net present value →			0

Figure 8. Calculation scheme for "Internal Rate of Return (IRR)

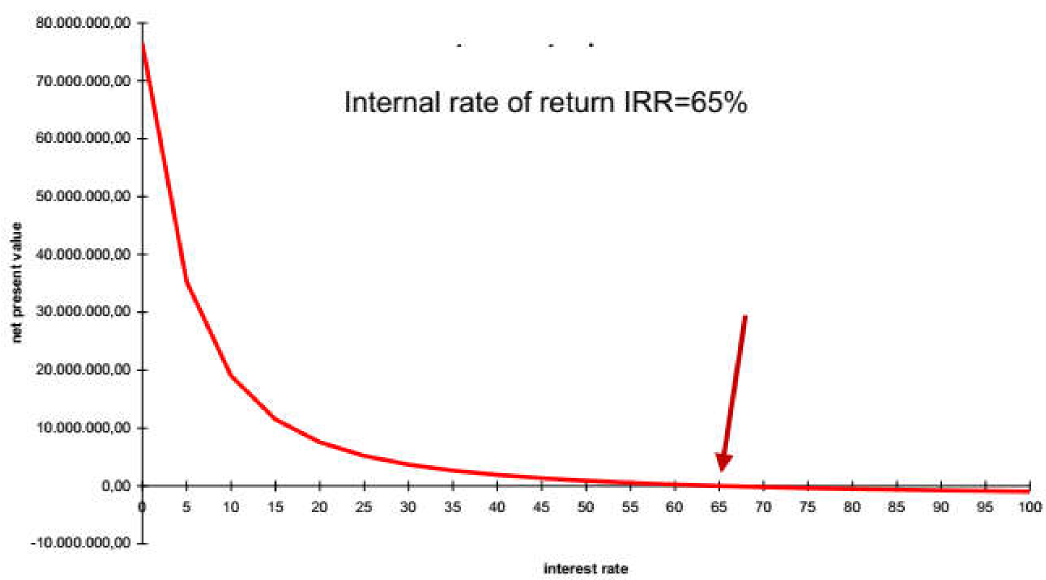

Figure 9. Presentation "Net Present Value" over "Interest Rate" (example: IRR at 65%!)

12. Summary

Track material development is ongoing. Strengthening ballast track towards longer geometry life and less ballast damage is strongly influenced by modern track maintenance technology and considerations on economy like LCC or IRR. IT-solutions are widely introduced in track geometry control and maintenance. Aligning track in accordance with fixed monuments and respective data-banks became standard in Europe.

Developments in rail steels and turnouts are not discussed in this paper.

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