WEAR ANALYSIS OF TILTING TRAINS USING “SIMPACK RAIL WEAR” MODULE

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ALSTOM Ferroviaria has developed, designed and manufactured, since the late sixties, different active tilting systems that allow increasing of speed in curves, while keeping high level of passenger comfort and running safety and low track aggressiveness. Up to now the systems have been installed above at least 320 trains in fixed composition, in revenue service on the principal European railway networks.

Further to the usual verification on safety and comfort, the possibility of simulating with the best possible accuracy the wheel-track damage and predict also the wear evolution on the wheels, is a challenge to face for a new product or in case of anomalous wear phenomena during revenue service.

This presentation describes the ALSTOM experience in this type of analysis using the “SIMPACK rail wear” module, that has been possible thanks to the tight collaboration of the SIMPACK experts. The case of study is related to a tilting train that runs on significant sections of the Italian Railway network.
The wheel profile monitoring of some trainsets showed a big dispersion in the mileage between two consecutive re-profiling of trainset operating in apparently similar conditions. First of all it is important is to “filter” all the field data and represent the cases related with “normal" wear only.

Some parameters have an influence on the wheel wear at different levels:

- **Vehicle characteristics** (Axle load, Primary suspension stiffness and geometry, Carbody / Bogie rotational stiffness, Motor or trailer axle, Traction / Braking forces & characteristics)

- **Wheel / Rail contact** (Wheel & Rail Profiles and rail cant, Wheel/Rail friction coefficient, lubricator device, Wheel material)

- **Operating conditions**: Curve radius and track cant in curve distribution, Mission profile.
Background (2/2)

SIMPACK now gives us the possibility to investigate the impact on the wheel wear evolution of one parameter or a combination of them already during the design phase.

The calculation procedure used:

- The SIMPACK validated model from Railway Dynamics point of view.
- A track design representative of the real train operating conditions.
- The corresponding Speed profile.
- The Virtual Testing Lab module of SIMPACK.

To check and set-up this methodology some simulations has been prepared and launched, based on:

- ETR600 vehicle (tilting train)
- Service line Firenze – Roma – Napoli, representative of the operating conditions of the real trainsets.

The choice has been done taking into account the availability of field data.
All simulations have been done using the model of ETR600

Main characteristics:

- The model is composed by 21 bodies (1 carbody, 2 tilting bogies, 2 bogie bolsters, 2 bogies, 2 traction link masses, 4 wheelsets, 8 axlebox), 97 Degree of Freedom.

- The connecting elements between bodies are modelled in realistic and reliable way, on the basis of the experience of ALSTOM Ferroviaria in this field.

- The bogies are modelled including all element of tilting and Hold off Device system (bolsters, kinematism with roods, actuators, sensors).

- a simplified control of the Hold off Device is sufficient.

- The vehicle model has been optimised focussing on the the need of wheel wear calculations.
Description of the SIMPACK vehicle model (2/2)

The SIMPACK model has been done to reproduce in the best way the functional characteristics of each suspension level:

**Primary suspension:**
- Two rods with elastic joints connecting the axlebox to the bogie frame (an articulated quadrilateral).
- Coil springs type “flexicoil” in parallel.
- Vertical damper and lower & upper stops.

**Secondary suspension:**
- helical springs type “flexicoil” in parallel on each side;
- Elastic bump-stops to control the lateral displacements between the carbody and the bogie;
- vertical & lateral dampers;
- Anti-yaw dampers.

**Tilting & Hold Off Device**
The model of the bogie is completed with tilting kinematism and actuators.

**Traction link:**
One mass (called “Z”) linked to the oscillating bolster through an elastic joint and to the bogie frame through two rods with elastic joints.
Overview on Model Validation Process

The SIMPACK model used in the wear calculation has been validated from the point of view of Railway Dynamics. Some model parameters and simulation results have been compared with the real vehicle characteristics and test results. In details:

1. Axle load
2. Lateral bump-stop displacement of secondary suspension.
3. Souplesse coefficient.
5. Quasi-static vertical load Q per wheel.
6. Track shift forces of guiding wheel during curve negotiation.
Track scenario

On the base of available field data, the following simulation scenario has been chosen to set-up the wear calculation procedure:

- 2 line sections:
  - “Direttissima” Firenze – Roma (Old High Speed Line).
  - Roma – Napoli (New High Speed Line).

- 2 running directions North → South and V.V.

- Total length for each cycle: 833 km.

- Total length reached: 30000 km.

- No track irregularity.

- Max speed 250 km/h (Max n.c.a. = 1.0 m/s²).

- Speed according to the real speed profile.
Wheel / Rail contact

- Wheel: S1002 (theoretical, according to EN13715) with Back to back space = 1360 mm.
- Rail: 60E1 (theoretical) with track gauge = 1435 mm and rail cant = 1/20.
- W/R Friction coefficient $\mu = 0.25$ (based on ALSTOM experience in this type of calculation).
- W/R contact Model: Elastic multi-point contact.

Vehicle conditions

- Vehicle suspensions in nominal operating condition.
- Vehicle Load: representative of the mean operating condition.
The following schema clarifies the structure of one cycle (around 800 km) of the simulation:

1. **Firenze** to **Roma** at 250 km/h on the “Dispari” track.
2. **Roma** to **Napoli** at 250 km/h on the “Dispari” track.
3. **Roma** to **Napoli** at 250 km/h on the “Pari” track.
4. **Firenze** to **Roma** at 250 km/h on the “Pari” track.

Simulation scenario and boundary conditions (3/3)
Wear law

All the simulation have been done using the Standard Wear Law.

This wear law implemented in the SIMPACK Rail Wear, is based on the theory of H. Krause and G. Poll for the adhesive wear: the volume (or mass) of the removed material is proportional to the amount of frictional work dissipated in the contact patch.

Two wear regimes are considered: mild and severe wear and the following parameters (found by Specht) have been used for the calculations:

- **Mild wear**: \( C_{\text{mild}} = 9.87 \times 10^{-14} \text{ m}^3/\text{J} \)
- **Severe wear**: \( C_{\text{severe}} = 9.87 \times 10^{-13} \text{ m}^3/\text{J} = 10 \cdot C_{\text{mild}} \)
Wheel wear parameters according to UIC 510-2

- **Sd** = Flange thickness, measured L3 [mm] from the tread line
- **Sh** = Flange height, measured between the tread line and flange tip
- **qR** = Flange gradient indicator, measured between L1 [mm] from flange tip and L3 [mm] from tread line

The wear analysis is completed with the superposition between nominal and worn wheel profiles to evaluate the most worn zones of the profiles and equivalent conicity analysis.
The following slides show the simulation results, in terms of:

- Wear parameters $S_d$, $S_h$ and $q_R$.
- Equivalent conicity $\gamma_{eq}$ related to the relative lateral displacement between wheelset and track $y = \pm 3$ mm.
- Profile shapes

These quantities are compared here with the field data related to the end vehicles of some trainset that run especially on the Line Firenze – Roma – Napoli.

The following figure clarifies the wheel profile identifications:
Analysis of simulation results: $S_d$, $S_h$, $q_R$
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Analysis of simulation results: $S_d$, $S_h$, $q_R$

Analysis of Wheel Wear Parameters: $S_h$
Comparison between Simulation results and Measured quantities

![Graph showing analysis of wheel wear parameters $S_h$](image)

- **SIMPACK Simulation**
- **MEASURED**
- **Linear (MEASURED)**
Analysis of simulation results: $S_d$, $S_h$, $q_R$

Analysis of Wheel Wear Parameters: $q_R$

Comparison between Simulation results and Measured quantities
Analysis of simulation results: $\gamma_{eq}$

Comparison between Simulation results and Measured quantities.
This slide completes the analysis of the results proposing the superposition between the simulated worn profiles and measured wheel profiles related to the same mileage and to the same bogies.
The Profile superposition shows a different distribution of the removal material in the wheel flange between the SIMPACK results and the measured profiles, in particular on wheelsets 2 and 3: this fact could be due to the simplifying hypothesis to consider constant in the simulation the value of wheel/rail friction coefficient along the wheel profile.
Problems & Proposals: **Time integration**

The following table summarises the mean CPU-time (integration + write) using Virtual Testing Lab (*) for one cycle of the simulation (833 km at 250 km/h):

<table>
<thead>
<tr>
<th>1 cycle = 833 km</th>
<th>Line sections</th>
<th>Total time spent for one cycle</th>
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<tbody>
<tr>
<td></td>
<td>Fi-Ro</td>
<td>Roma-Na</td>
</tr>
<tr>
<td>0. New wheel profiles</td>
<td>~ 2210 sec.</td>
<td>~ 1370 sec.</td>
</tr>
<tr>
<td>1. Worn wheel profiles</td>
<td>~ 6180 sec.</td>
<td>~ 4440 sec.</td>
</tr>
<tr>
<td>2. Worn wheel profile smoothed “manually”</td>
<td>~ 2470 sec.</td>
<td>~ 1790 sec.</td>
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To reach 30000 km of mileage:

- in case 1: about 9 days with distance factor = 1.
- in case 2: about 4 days (projection) with distance factor = 1.

This problem is directly linked to the profile smoothing problem, described in the next slide.

**Note:** (*) CPU Intel core i5 2.4 GHz, RAM = 3.4 GB
Problems & Proposals: Profile smoothing

SIMPACK rail wear calculates the worn profiles subtracting the removed material from the wheel profile in each point, without any smoothing.
Due to this calculation procedure two different problems have been found:

1. The **Distance Factor**: Using the "Distance factor", not realistic worn wheel profiles (local hole in particular on the flange) could be found.

   To avoid this problem all simulation have been done using Distance Factor = 1
   \[ \text{increasing of calculation time.} \]

2. The **undulation of worn wheel profile**: even using the distance factor = 1, the tread of the worn profile present a very small undulation, but sufficient to penalize the integration algorithm performance.

   Some time the calculation has been stopped and all worn profiles have been smoothed “manually”, using “Wheel rail profile approximation”. This method solves the problem, but increasing excessively the calculation time.

**Proposal**: A “Profile Smoothing” tool to optimize the calculated worn profile from the point of view of the integration algorithm. This should reduce significantly the calculation time and increase the reliability of the prediction results.
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Problems & Proposals: Wear Distribution

The following figures show the superposition and the difference in vertical direction between the New wheel profile and a worn profile generated by SIMPACK rail wear for two different mileage: 5000 km and 25000 km.

The comparison indicates an unexpected wear on the flange (red circle): during the simulation the wheel / rail contact point don’t arrive in this zone of the wheel profile. This fact have to be investigated.
SIMPACK rail wear can produce a lot of relevant output channels, but it doesn’t calculate the wear parameters according to UIC 510-2.

For this reason, an external tool has been developed to translate the SIMPACK worn profile file in a format and in a reference system compatible with commercial software for the wheel/rail profile analysis.

As consequence, for each SIMPACK calculation cycle, the following steps was done to obtain the Sd, Sh and qR parameters and other significant results:

**SIMPACK output:**
- WS1L_s1002_BEFORE_00x.wp
- WS1R_s1002_BEFORE_00x.wp
- WS2L_s1002_BEFORE_00x.wp
- WS2R_s1002_BEFORE_00x.wp
- WS3L_s1002_BEFORE_00x.wp
- WS3R_s1002_BEFORE_00x.wp
- WS4L_s1002_BEFORE_00x.wp
- WS4R_s1002_BEFORE_00x.wp

**ALSTOM Tool**
- ETR600_01-sx-***km.lh2
- ETR600_01-dx-***km.lh2
- ETR600_02-sx-***km.lh2
- ETR600_02-dx-***km.lh2
- ETR600_03-sx-***km.lh2
- ETR600_03-dx-***km.lh2
- ETR600_04-sx-***km.lh2
- ETR600_04-dx-***km.lh2

**Commercial Software for wheel/rail profile analysis**
- Sd, Sh, qR
- $\gamma_{eq}$
- $\Delta R(y)$
- ...

Proposals (alternative):

- A tool to calculate Sh, Sd and qR could be added to SIMPACK rail wear.
- The worn wheel profiles could be write also in a format compatible with commercial software (e.g., Miniprof format).
The SIMPACK version 8.904 can’t perform a simulation with New Contact Model, Wear Module and Virtual Testing Lab: after each cycle the wheel profiles are not up-dated.

Only single run can be done.

Since:

- The next version of SIMPACK will not include the Classic Contact Model.
- The worn wheel profiles definition and managing is easier in the New Contact Model than the Classic one.
- The integration time is in general lower using the New Contact model that the Classic one

Solving this limitation is of high priority.
Conclusions

Strength points

➢ The SIMPACK rail wear is quite interesting for product development.

➢ Simulation costs much less than field testing, in case of wear issues.

Weak points

➢ Calculation time is actually very high. Optimization of Integration and smoothing necessary to speed-up the process.

➢ Some improvements could be necessary to optimize the integration of the model with worn profiles and to generate automatically the outputs required by the standard.

➢ The combination SIMPACK rail wear + New Contact Model have to be investigated.