DYNAMIC SIMULATIONS OF TALGO TRACK-INSPECTION TRAINSET

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ABSTRACT

In this paper, a brief description of the model and real prototype for track auscultation will be done. Both dynamic results and their matching with real test runs carried out in Spain with Talgo rolling stock will be shown.

The purpose of the dynamic calculations was to verify that the requirements according to the leaflet UIC518 (Testing and acceptance of railway vehicles from the point of view of dynamic behaviour, safety, track fatigue and running behaviour) were respected, for 1668-mm gauge as well as for 1435-mm gauge. Just as short reminder: the Track Inspection train is equipped with the variable gauge system developed by Talgo, and it is capable of running on both track types.

The study was focused on the end car, conceived as driving trailer and furnished with a free wheel rolling assembly and automatic gauge change system.

I.- BUILDING THE MODEL

TRAINSET FOR TRACK AUSCULTATION

One power head with gauge change system (Talgo BT locomotive) will compose this trainset, equipped with a driver´s cab at the end. In addition, one intermediate car and a laboratory coach complete the whole train.

We were more interested in he dynamic behaviour of the first and second Talgo wheelsets including the driver´s cab. That is because the behaviour in the rest of the elements that form the trainset it was already known. The running direction chosen for carrying out dynamic simulations was with the driving cabin on the head presuming a worse dynamic response in such condition. In figures 1 and 2 are represented both model and real prototype.

This trainset is able to operate on tracks with different gauges due to the fact that its locomotive has a bogie with a gauge changing system. All the Talgo wheelsets (with independent wheels) are able to change their gauge as well. So the test runs in the simulator have been done using both 1435 and 1668 mm track gauge. A better running behaviour was expected in case of 1435-mm gauge (UIC).

A brief description of the Talgo wheelset with independent wheels, BT locomotive's bogie, carbodies, car's attachments and specially the Talgo guidance system will be done next.

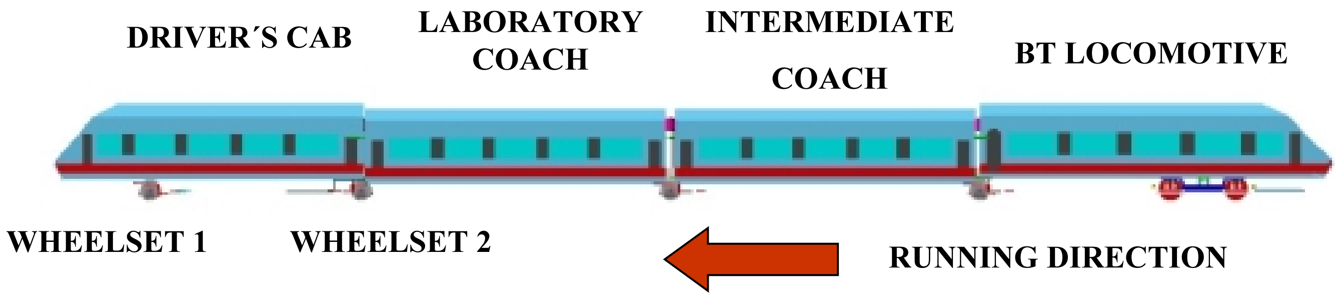


Figure 1: ADAMS Talgo-trainset model

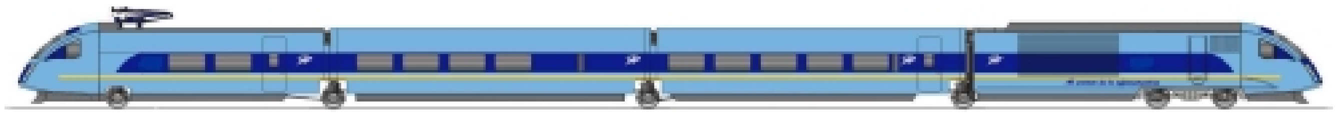


Figure 2: Talgo real trainset for track auscultation

BUILDING TEMPLATES

Wheelsets

<u>BT locomotive Bogie</u>

The most important feature of this wheelset is that it is the only one with rigid axle in the whole Talgo trainset. This element has been modelled considering its track gauge changing capacity. That means that an additional frame has to be used as non-suspended mass attached to each axle of the double wheelset. Those frames reinforce the variable gauge axles that are slotted against bending deformation and they must be considered mainly because of their effect on contact forces.

Two trailing arms are used for attaching each reinforced frame to the bogie frame. Bushings with a specific stiffness are located in the trailing arms as joints. Their stiffness have to be defined properly in order to avoid lifting the inner wheel when performing simulation in curves as happened at the beginning of our experience with ADAMS Rail.

Four primary suspension elements (maize colour- figure 3) and dampers (blue colour) are used for each axle. Two secondary suspension elements are located in both sides of the bogie frame (in green colour).

Anti-yaw (red colour), lateral (yellow colour) and vertical dampers (maize colour) were used as well (see figure 3).

Finally the so-called traction bar is placed between the bogie frame and the BT locomotive by means of bushings.

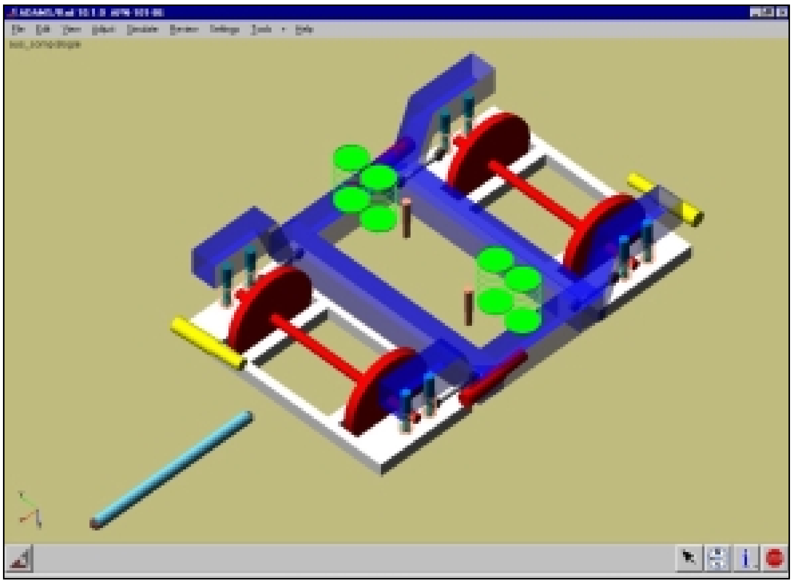


Figure 3: BT Locomotive bogie template

Talgo wheelset.

Rolling on independent wheels this wheelset is formed by a yoke, a couple of columns or supporters, lateral bumpstops yoke-coach, airsprings on the top, lateral dampers yoke-coach at the bottom and a mechanism for wheelset steering (see figures 4 and 5). Since independent wheel axles are not able to guide themselves it is necessary to do it with external aids, i.e., an external mechanism that keeps the wheelset centred on track.

The yoke is made of an extrusion and together with the columns it forms a single part in ADAMS. There is no primary suspension in all these wheelsets. The airsprings lean on the columns and support the weight at the end or rear of the Talgo carbody near the coupling between cars.

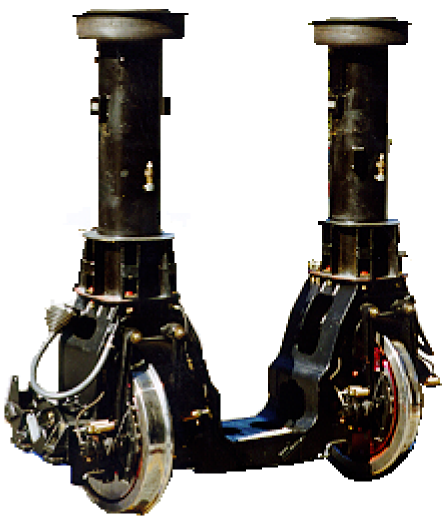


Figure 4: Talgo wheelset (real prototype)

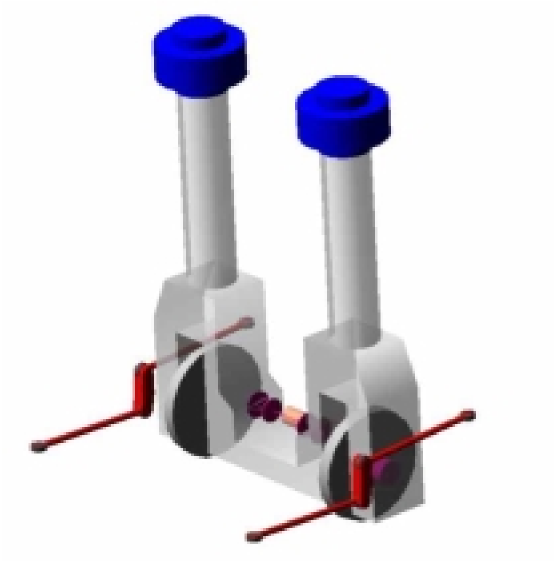


Figure 5: Talgo wheelset (ADAMS Template)

Different types of profile have been defined for both locomotive and rolling stock wheelsets. In case of independent wheels the profile slope is much higher, about 5%, than in the BT wheelset (see figures 6 and 7).

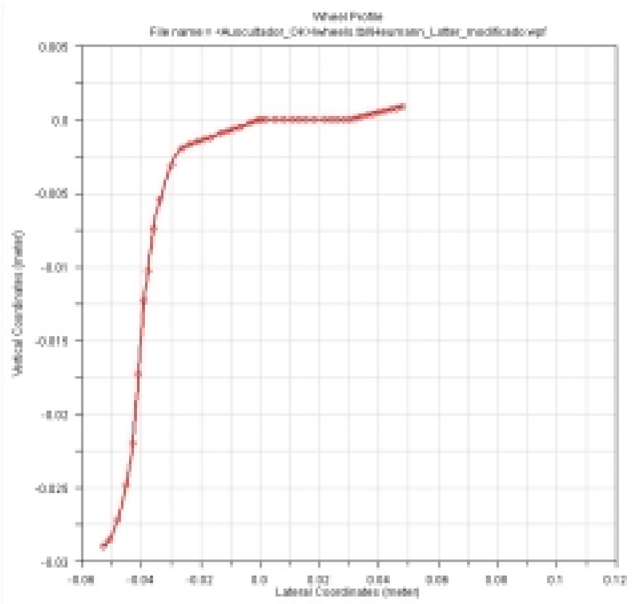


Figure 6: Heumann Lotter profile (BT bogie)

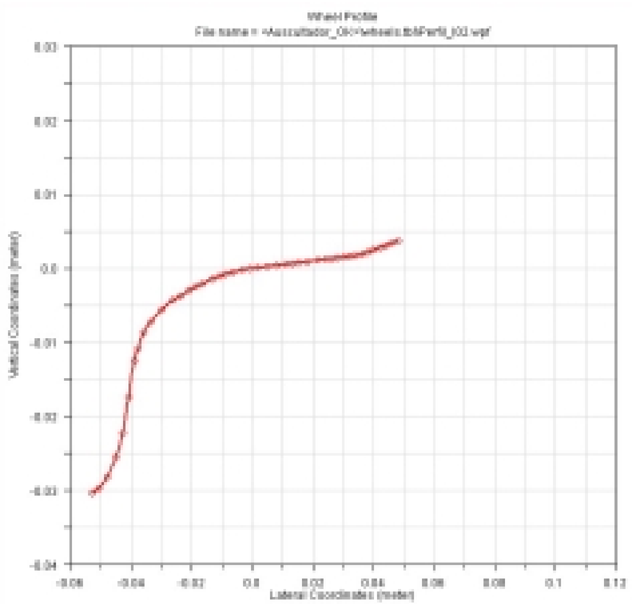


Figure 7: IO2.317 profile (Talgo RS)

Airsprings

Nishimura airsprings are used for simulations in curves in order to allow tilting and Krettek airspring should be used in straight track simulations with double type control.

Anyway there is only one exception about it, just one of the carbodies (laboratory coach) leans on two Talgo wheelsets. The front wheelset uses Krettek airsprings with single control in all cases, so that the laboratory coach essentially leans on three points.

Talgo wheelsets are located in all points of articulation and at the end of the trainset (driving cabin with no traction). The so-called "rodal" (Talgo wheelset in Spanish) at the end position has a more tricky guidance system that will be explained afterwards.

For guiding the intermediate Talgo wheelsets a mechanism like the one represented in figure 8 will be used. An equaliser beam with a revolute joint beam-yoke applies the guiding forces in both sides. That beam works by means of push/pull guidance rods, which are connected to the adjacent cars. Rods are attached to beam and carbody thanks to bushings with different stiffness in each case. Their elasticity has an important role in the right way of guiding when negotiating curves. See in figure 8 a detail of the guidance mechanism.

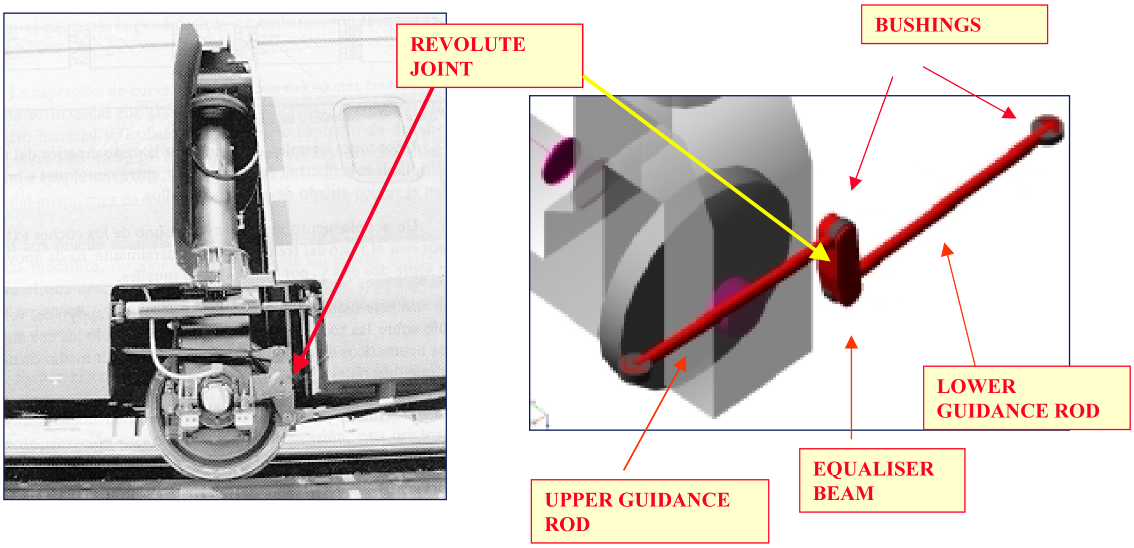


Figure 8: Guidance mechanism (real prototype/ ADAMS model)

How does the intermediate guidance system work?

When the trainset is entering a curve the inner side of the head coach pushes the inner front rod (whatever lower or upper). At the same time the outer side of the head coach pulls the outer front rod. Since the rear coach is still on straight track, rear rods do not move, so that both ends of the rear rods and consequently one beam end stay fixed with respect to the rear coach. For that reason, front rods are able to move the non-fixed beam end forward to the outside and backward to the inside of the curve

In figure 9 the guidance system is shown working in full curve.

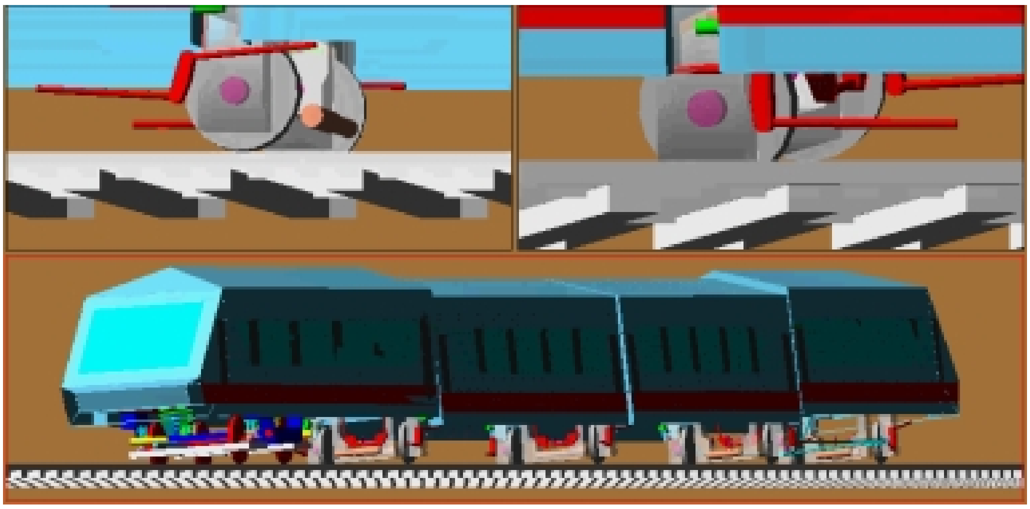


Figure 9: Intermediate guidance system working (outer and inner wheels)

The front coach is pulling the lower front rod to the outer side of the curve (see top-left frame) so that it introduces a clockwise rotation of the equaliser beam. Inside the front coach is pushing lower rod (see top-right frame in figure 9) and beam rotates in the opposite direction (note that the point of view changes in figure 9: the left and the right side of the wheelset are represented).

Essentially, the guidance system tries to keep permanently the wheelset central axis within the bisector line between coaches.

How does the extreme guidance system work?

This case is an exception because the angle between laboratory and cabin coaches is responsible of the extreme wheelset steering. The point of information (articulation between coaches) is 8.97 meter far from the point of action (extreme wheelset steering) so that there will be a small delay or advance of the extreme wheelset steering. Figures 10 and 11 show this mechanism.

Inner driving rod together with driving beam and longitudinal rods rotates counterclockwise both crank arms. These arms substitute the carbody moving the guidance rods of the extreme axle. Almost all this mechanism has been built with spherical and revolute joints for modelling its performance.

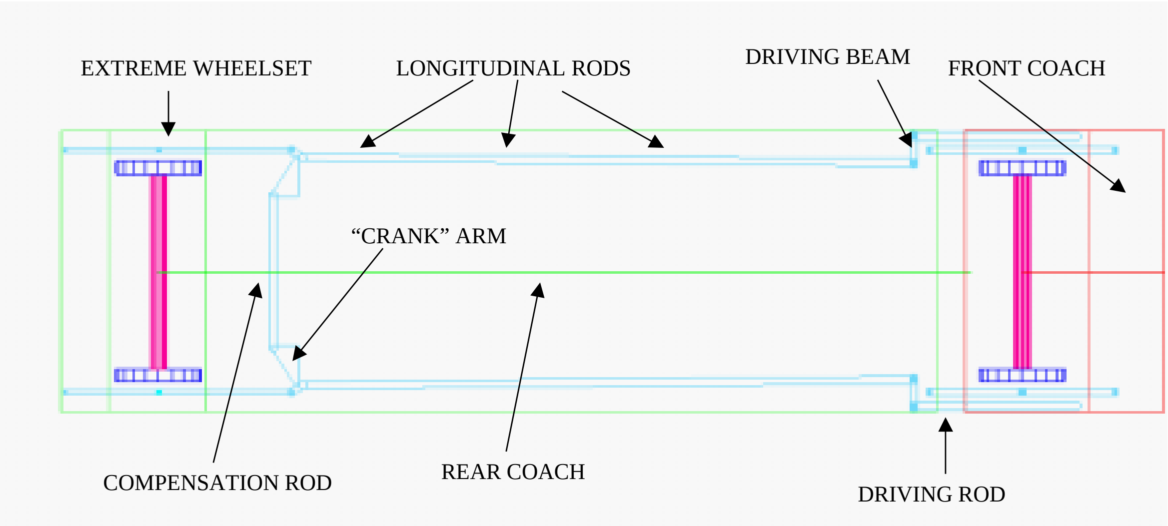


Figure 10: Extreme wheelset guidance system (on straight track)

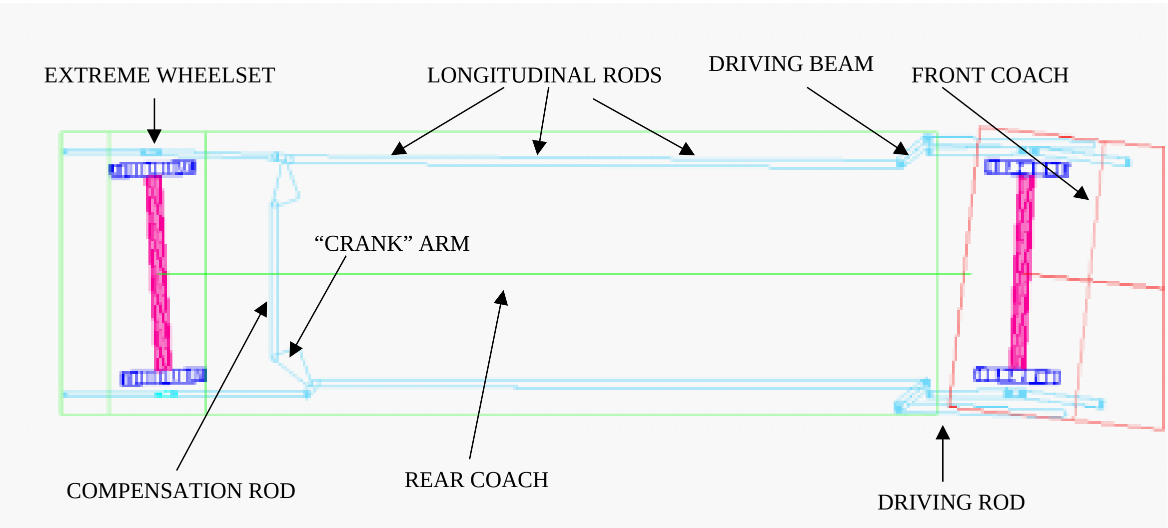


Figure 11: Extreme wheelset guidance system (on curved track)

Carbodies

Four different carbodies have been considered in this model. All data regarding their masses are without passengers' load because of the purpose of this trainset. It has been necessary to build one template for each carbody due to the special features they have in each case. Those attaching differences can be seen in figure 15

Carbody attachments

Weightbearer mechanism

Between carbodies there are longitudinal and lateral damper, upper bumpstops, couplings and finally the bearer mechanism.

The weightbearer mechanism has two important tasks:

- It permits the end of each coach but laboratory being hung or suspended by the next one
- It also enables relative rolling movements between carbodies

This mechanism has been modelled using spherical and revolute joints.

Figure 12: Carbody attachments

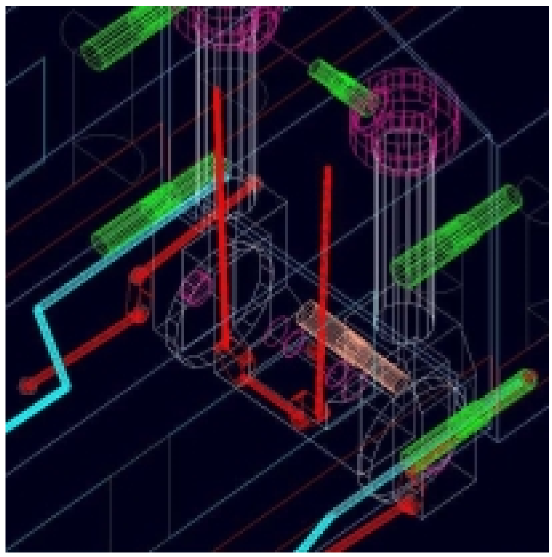


Figure 13: Weightbearer mechanism

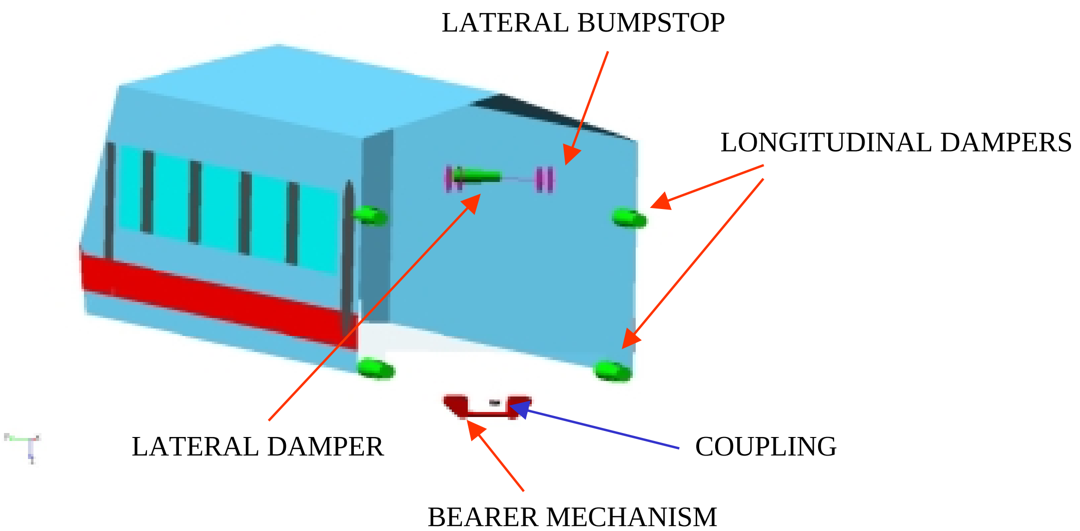


Figure 14: BT locomotive carbody

Couplings

Bushings have been used as couplings between carbodies. The most important feature of these ones is the X- axis stiffness. The selection of the Y and Z-axis stiffness is actually very important for the dynamic behaviour of the coaches.

Template communicators

Most of the input communicators were placed in Talgo wheelsets regarding guidance system rods, lateral dampers and yoke-carbody bumpstops. BT Bogie is attached to BT locomotive by the push/pull bar and the secondary suspension. Coaches containing couplings and lower part of the weightbearer system also include input communicators for connecting with the adjacent coach.

Output communicators are placed mainly in carbodies.

The subsystems with their car order are shown in figure 15.

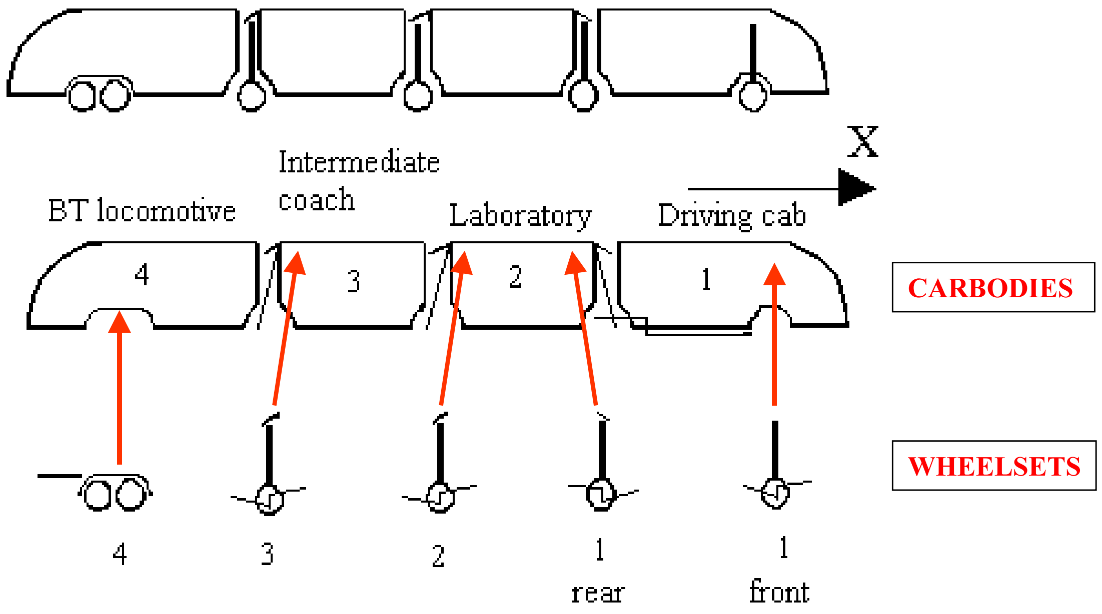


Figure 15: Main trainset attachments and subsystems

Lateral and vertical carbody acceleration requests (sensors)

For measuring lateral and vertical acceleration on passengers it was necessary to create a specific function. For example, if we are interested in the driver´s cab centre mass lateral and vertical acceleration the following functions should be used

$$F2 = ACCY(13,11,11) \cdot COS(AX(13,12)) - 9.8 \cdot SIN(AX(13,12))$$

$$F6 = ACCY(13,11,11) \cdot SIN(AX(12,13)) + ACCZ(13,11,11) \cdot COS(AX(13,12))$$

Being markers 13 = CM; 11= origo and 12 = speed reference in the carbody template. Consequently F2 is lateral acceleration and F6 vertical acceleration both on centre of mass of the carbody.

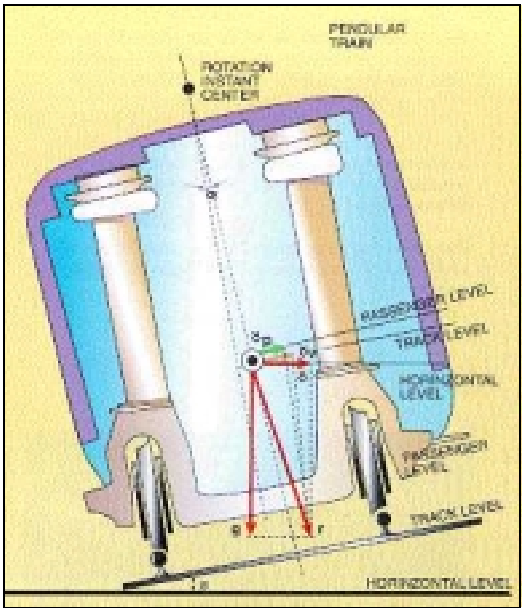


Figure 16: Carbody´s centre of mass lateral acceleration

The results obtained using those requests are shown in the following figure.

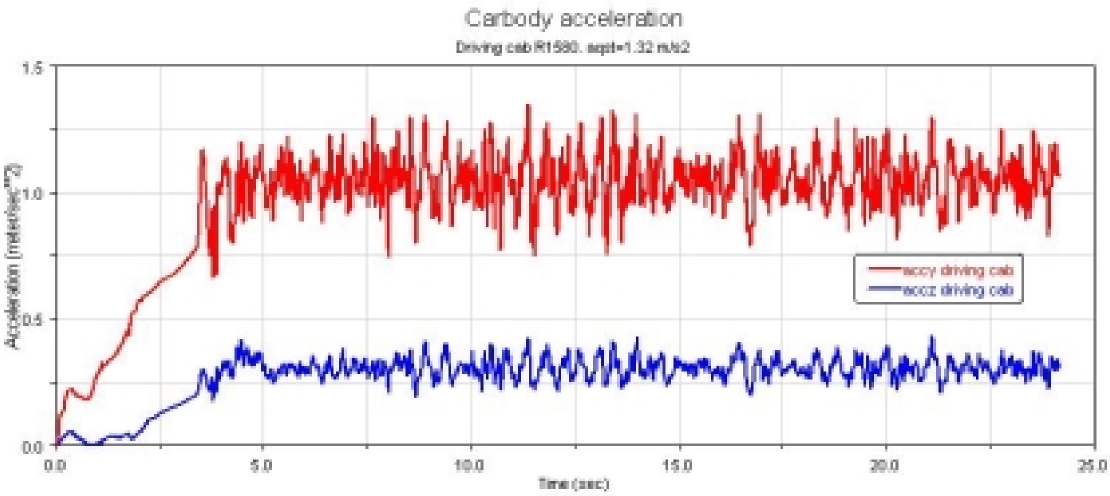


Figure 17: Centre of mass lateral/vertical acceleration (driving cab). Aqst = 1.32 m/s²

II.- DYNAMIC SIMULATIONS (RESULTS AND MODEL FEEDBACK)

The simulation conditions were the following:

- Vmax = 200 km/h + 10%, for simulations on straight track or in wide radius curves
- Aqst = 1.2 m/s2 + 10 %, for tracks with curves having a radius between 300 and 500

Different track qualities (QN1 y QN2) have been used, scaling actual track data provided by RENFE.

The dynamic simulations that have been carried out were focused on the driver´s cab on head. The first and second Talgo wheelsets were analysed as well according with to UIC 518 leaflet.

It has to be reminded that the only non-tilting carbody is the BT locomotive due to the fact that its longitudinal suspension axis is lower than its centre of mass.

1. Simulation at 220 km/h on straight track, (1435-mm gauge and QN1 track-irregularities)

Safety

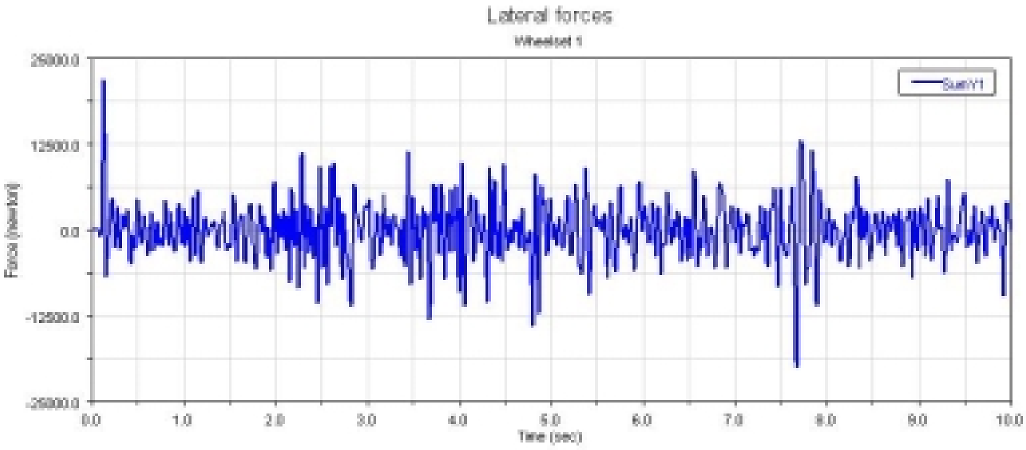


Figure 18: Lateral force on wheelset 1

In figure 19 it is possible to see bigger amplitude of the rigid axle lateral displacement signal than with independent wheels. This also happens with the angle of attack (figure 20)

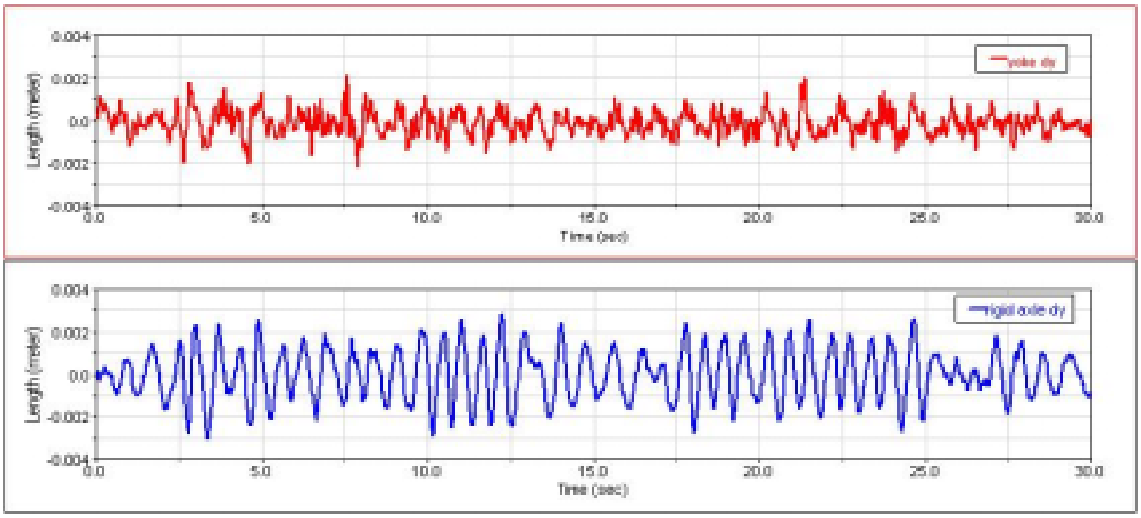


Figure 19: Lateral displacement (independent wheels axle/rigid axle)

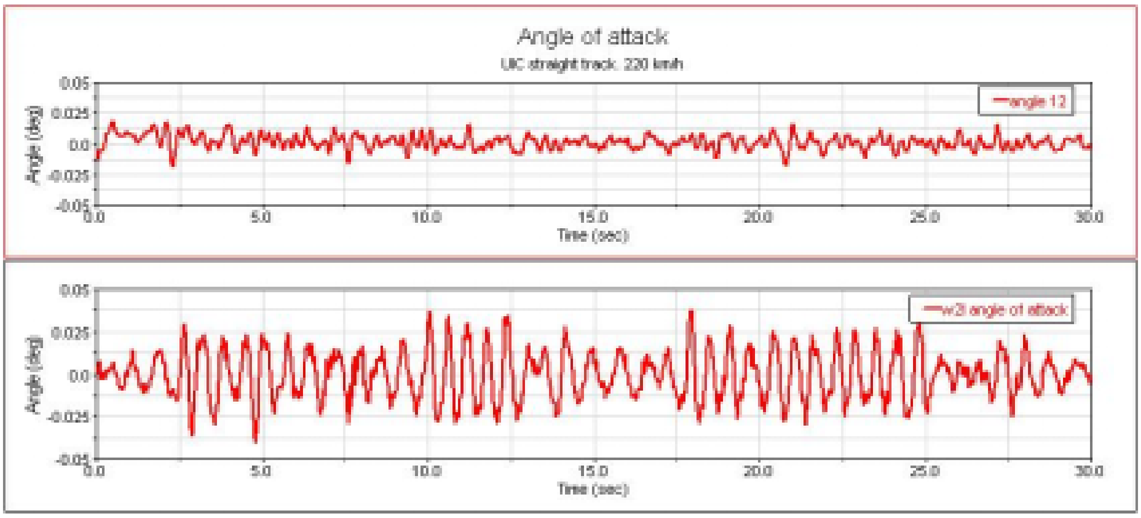


Figure 20: Angles of attack (Talgo/Bogie WHEELS)

Running behaviour

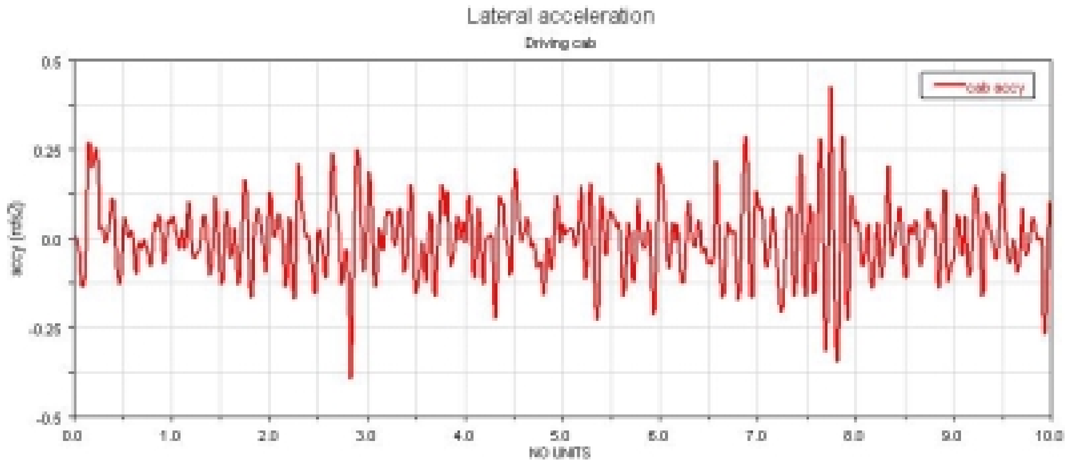


Figure 21: Driving cab lateral acceleration on straight track

2. Simulation at 1.32 m/s^2 of uncompensated acceleration on curved track with small radius (R= 1580 m, 1668-mm gauge and QN1 track-irregularities)

Safety

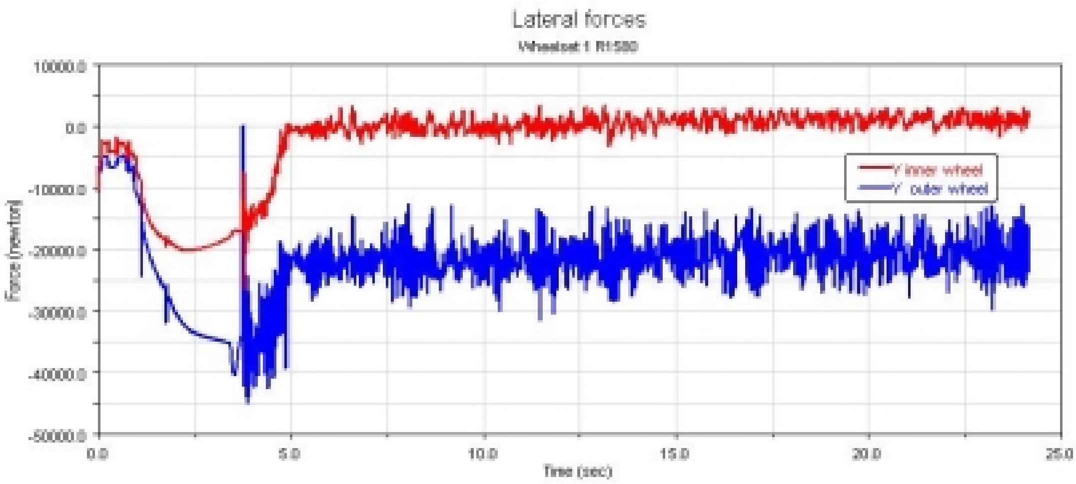


Figure 22: Lateral forces on wheels (wheelset 1)

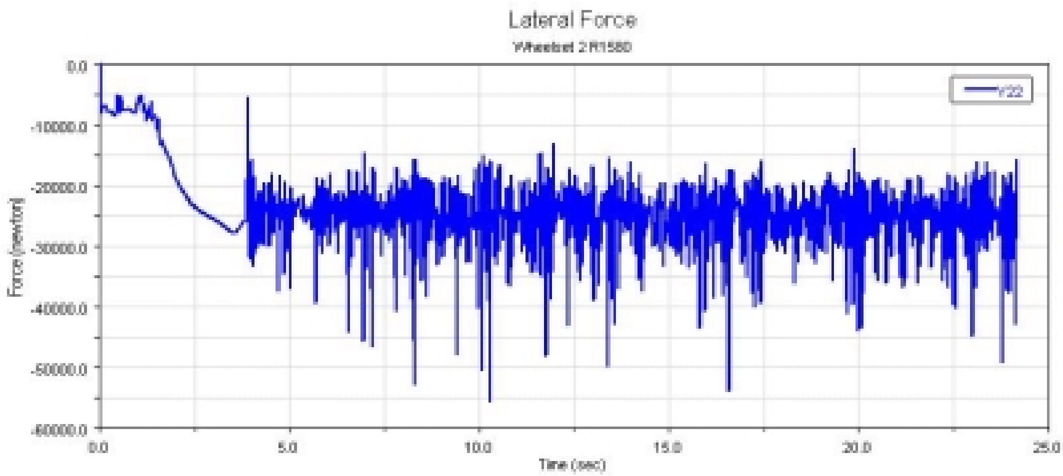


Figure 23: Lateral force on external wheel

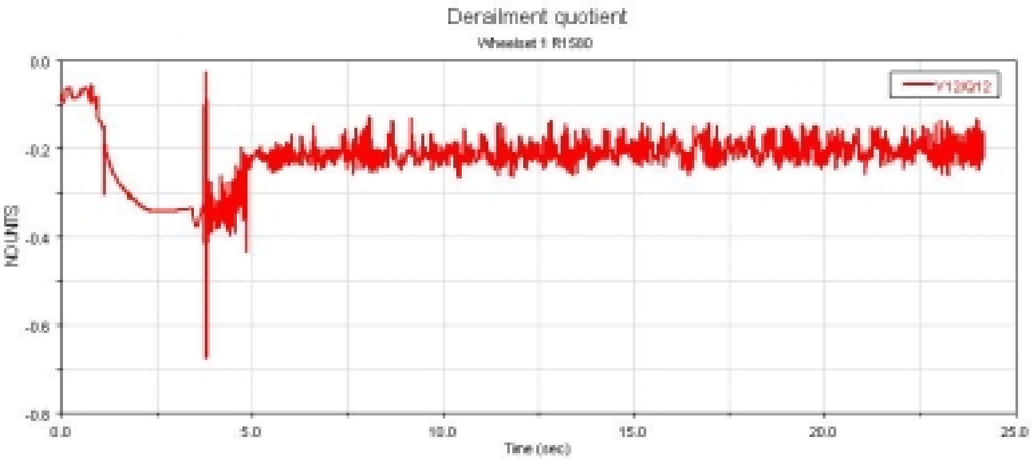


Figure 24: Derailment quotient Y12/Q12

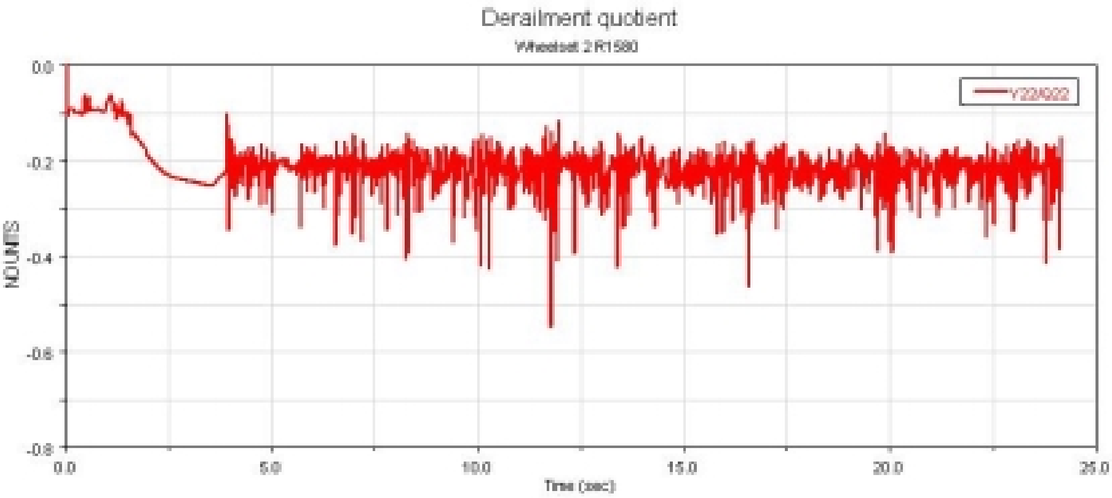


Figure 25: Derailment quotient Y22/Q22

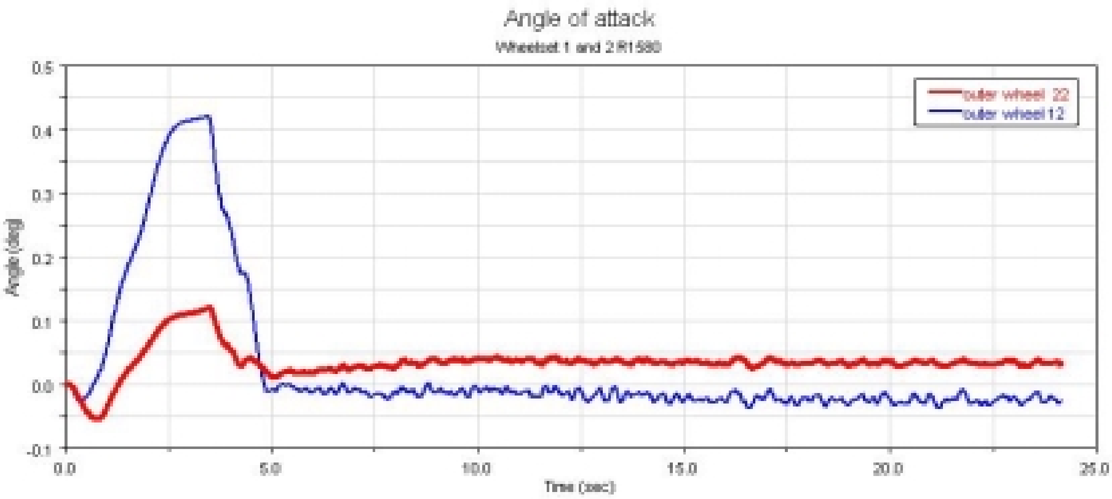


Figure 26: Angle of attack. Wheelsets 1 and 2 (outer wheels)

Track fatigue

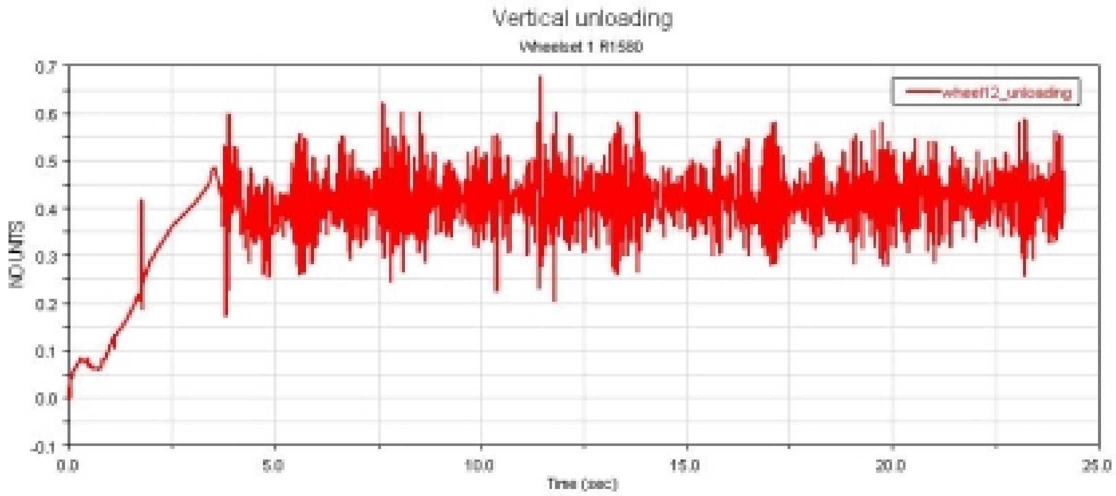


Figure 27: Wheelset 2 unloading

Running behaviour (lateral and vertical acceleration on carbody):

Average lateral acceleration on passenger is reduced to 1 m/s^2 when having an uncompensated acceleration of 1.32 m/s^2. The reason is the additional cant in curves thanks to the natural tilting system.

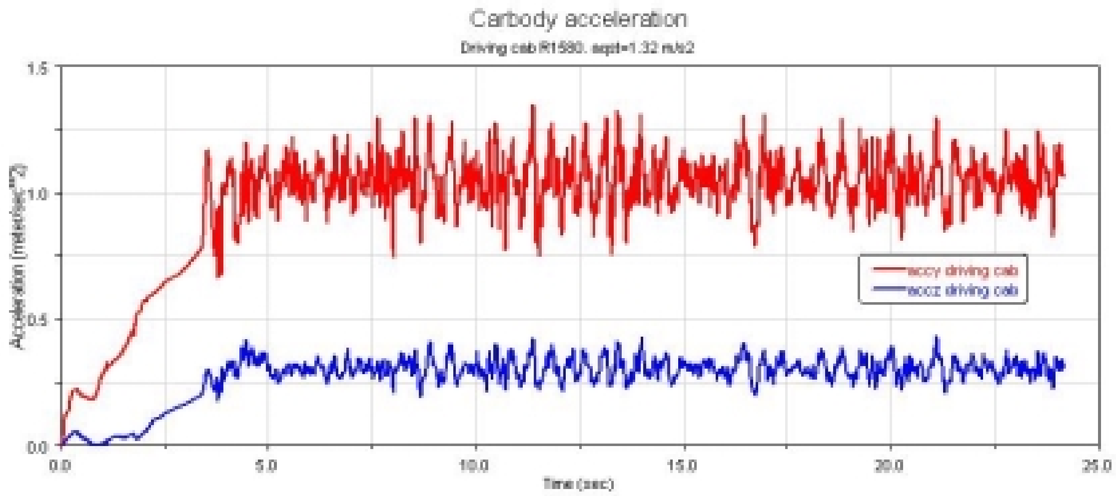


Figure 28: Centre of mass lateral/vertical acceleration (driving cab). Aqst= 1.32 m/s^2

3. Simulation at 1.32 m/s^2 of uncompensated acceleration on curved track with large radius (R= 500 m, 1668-mm gauge and QN1 track-irregularities)

Track fatigue

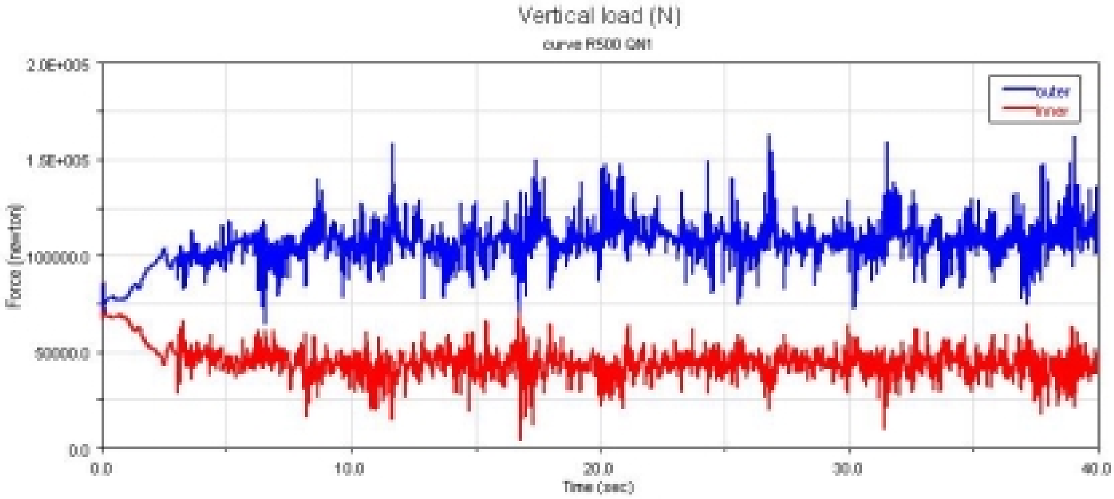


Figure 29: Vertical contact forces on wheels (axle 1)

Figure 30 shows the roll angle of the BT locomotive and the laboratory coach. It is worthwhile noticing that rolling angle is the biggest in case of Talgo coach and bigger than the Talgo wheelset-rolling angle (without primary suspension). Consequently the Talgo coach is moving inward curve and the BT locomotive outward. The different rolling behaviour is enabled by the weightbearer mechanism.

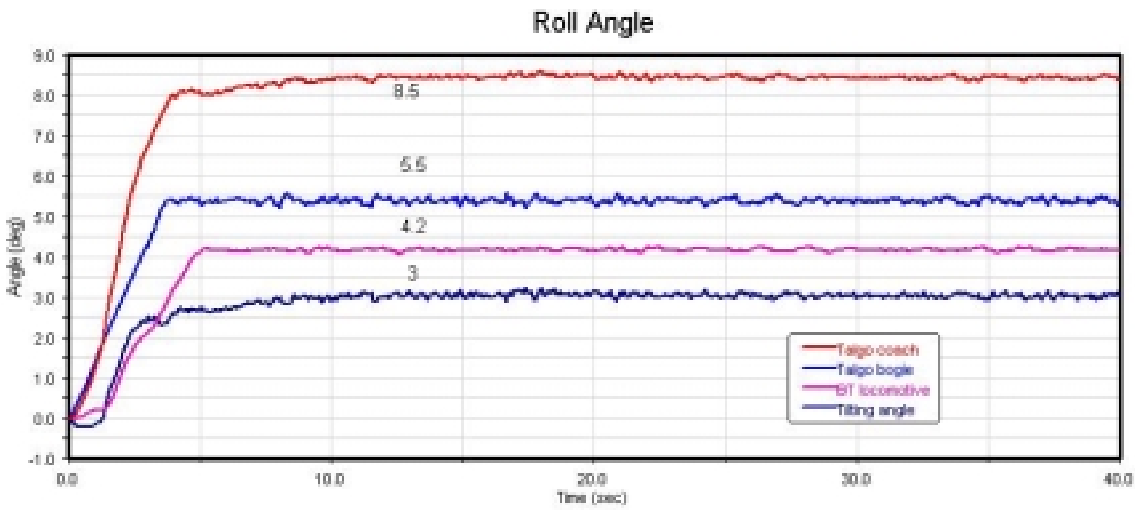


Figure 30: Tilting angle (Talgo coach)

Postprocessing

For obtaining the UIC 518 leaflet required indexes and making statistical calculations it was necessary to export specific results into data files. After that specific software (DATATEST 2000) was used for those statistical calculations. DATATEST 2000 is able to read and process measured values from real test runs and result sets from dynamic simulations. With a 3D matrix (dynamic variables, statistical variables and track sections) it is possible to calculate all indexes of assessment quantities. Next it is shown an example of a performed dynamic report in our Department. The graphics include the results by sections and the black horizontal line represents the calculated indexes. In red colour the UIC limit. Obviously the number of track sections will be very small because of the track length used in simulations. See below in figure 31 an example of a real case of comfort study.

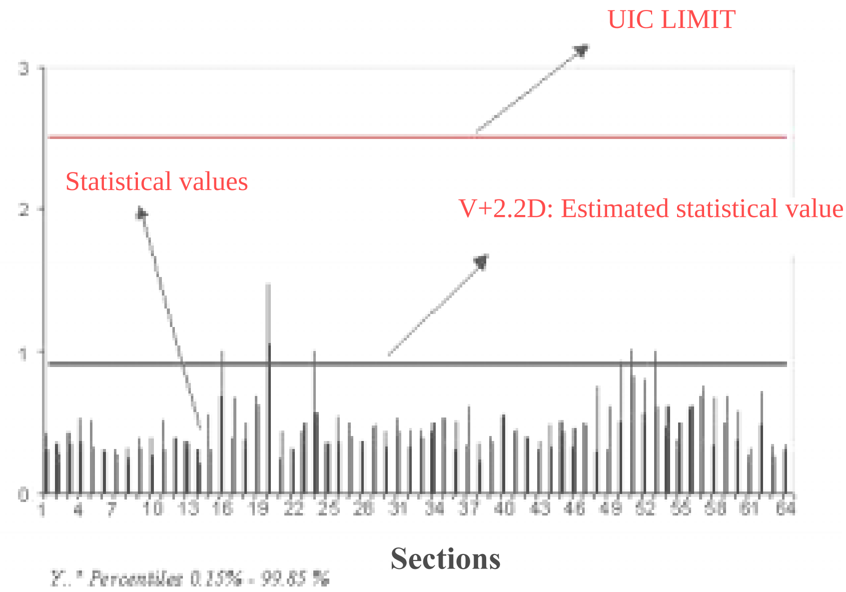


Figure 31: Lateral acceleration on carbody. Comfort study

COMFORT STUDY

Rolling Stock Dynamics Department

Date 19/3/01

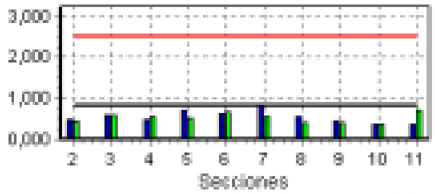
Hour 17.07.34

Study Code: RENFE gauge track ***Small radius curve***

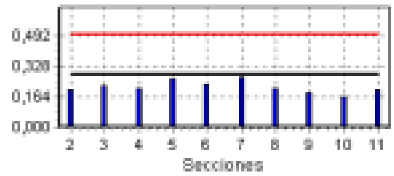
Test track: Radius 500-m **Track irregularities quality** QN2

Running direction: driving cab ahead

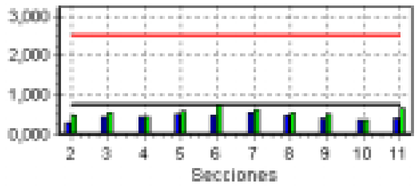
Initial Velocity (km/h): 124 **Trainset:** Track auscultation



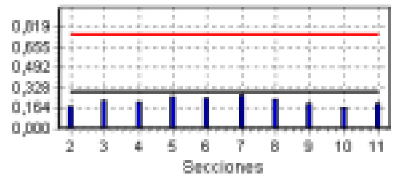
Y..*CAB - Percentiles 0,15% - 99,85% ( )



Y..*CAB - RMS ( )



Z..*CAB - Percentiles 0,15% - 99,85% ( )



Z..*CAB - RMS ( )

SAFETY STUDY

Rolling Stock Dynamics Department

Date 26/3/01

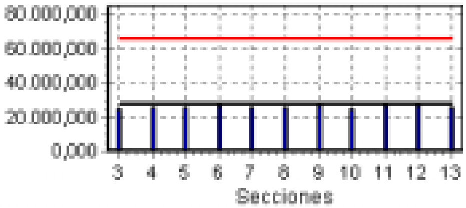
Hour 9.55.18

Study Code: RENFE gauge track **_Large radius curve_**

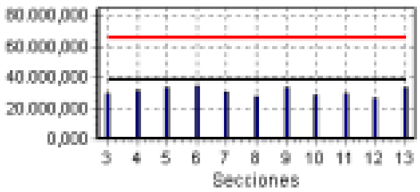
Test track: Radius 1580-m **Track irregularities quality** QN1

Running direction: driving cab ahead

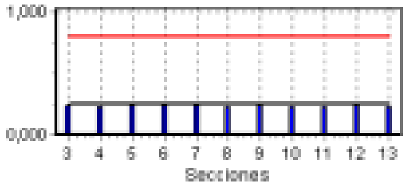
Initial Velocity (km/h): 220 **Trainset:** Track auscultation



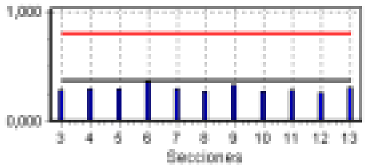
SumY1-Vm2m – Max. percentile 0,15% -99.85%



SumY2-Vm2m – Max. percentile 0,15 %-99,85%



Y12/Q12-Vm2m – Max. percentile 0,15% -99.85%



Y22/Q22 - Vm2m – Max. percentile 0,15% -99.85%

III.- MODEL FEEDBACK AND IMPROVEMENTS

Nishimura airsprings heights in curve

In order to get the right tilting behaviour it was necessary to decrease the vertical and lateral stiffness of couplings between coaches. The problem we had consisted of both airspring heights (outer and inner in curves). They were decreasing and we wanted the outer one to increase and the inner to decrease. In figure 32 the airspring displacements in the inside and outside of a curve with 1.32 m/s^2 of uncompensated acceleration are shown. In figure 35 the measures of the same variables in real test runs carried out in Spanish tracks are represented. Those are absolute values.

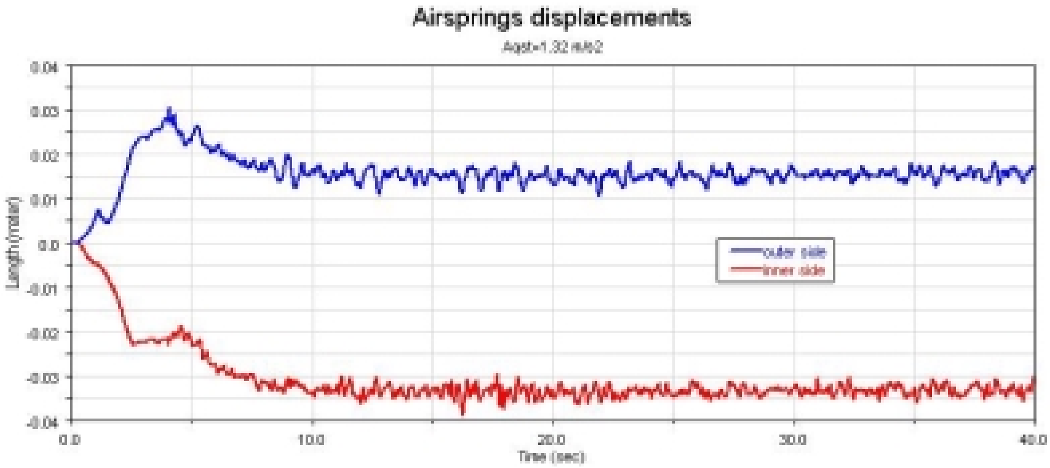


Figure 32: Airspring relative displacements (outer/ inner sides)

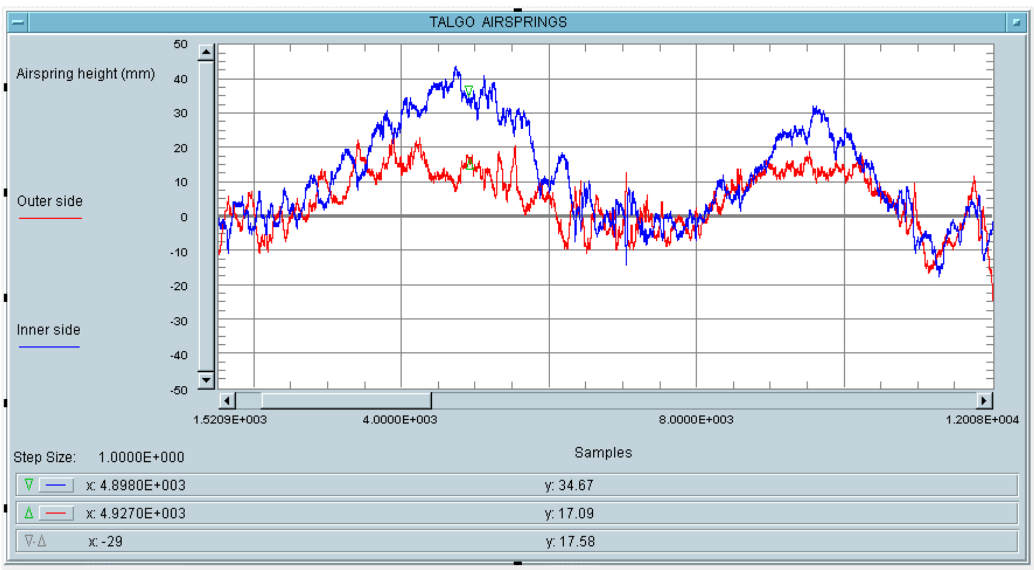


Figure 33: Real Talgo airspring displacements in curve (aqst = 1 m/s^2). Absolute values

Double wheelset vertical dynamic behaviour

When dynamic simulations were done with curves of small radius, inner wheels of the bogie lift and lost contact. So, we had to decrease the stiffness of the bushing, which are located in trailing arms. Those bushings together with the outward inclination of the bogie frame led to wheel lifting in curves.

Mechanisms

The selection of the right combination of spherical joints, revolute joints and bushing took much time for the extreme axle guidance system. There was no possible convergence of the solver equations when making static and dynamic simulations. We had similar difficulties modelling weightbearer mechanism because using an excessive number of constraints (many revolute joints) led to the same convergence problems.

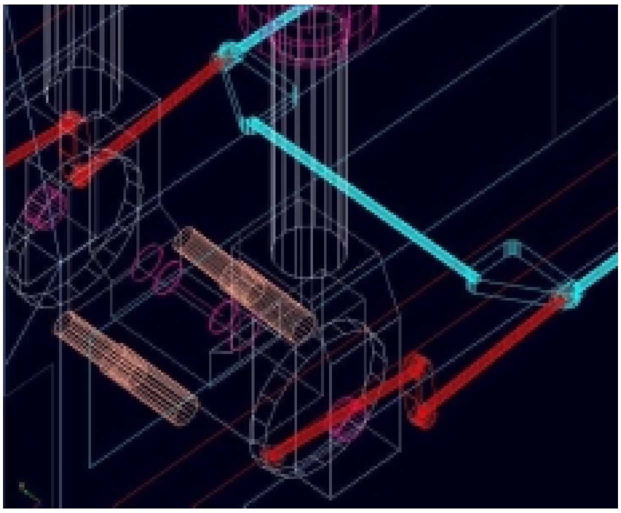


Figure 34: Extreme wheelset attachments

The very best combination of rigid joints used in the extreme mechanism is shown in figures 35 and 36.

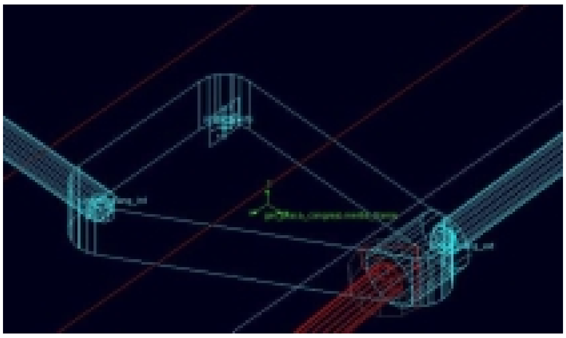


Figure 35: Crank arm joints

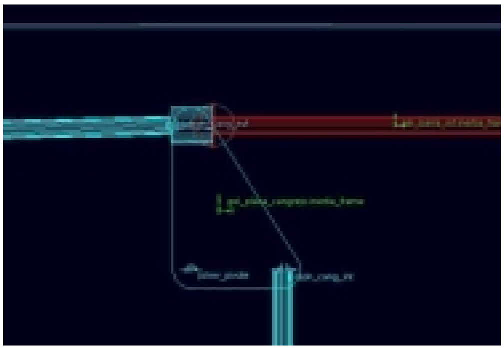


Figure 36: Crank arm (top)

Another combination of rigid joints used in the weightbearer mechanism is shown in figure 37.

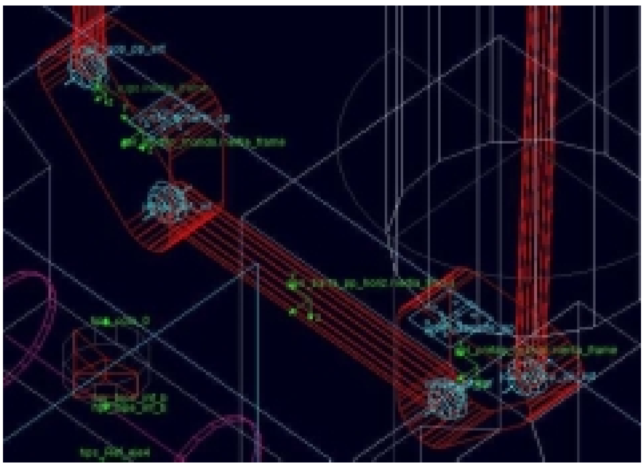


Figure 37: Weightbearer mechanism joints

IV.- CONCLUSSIONS

The results achieved in dynamic simulations have been coherent regarding tilting in curves, lateral and vertical accelerations on carbodies, contact forces and guidance system. However, lateral contact forces and derailment quotients are very sensitive to guiding behaviour. Maybe the use of adequate bushings between axleboxes and Talgo yokes could fix that problem.

The use of bushings in trailing arms and couplings has to be very accurate in their stiffness definition in order to get right results. Also the appropriate combination of joints has to be chosen to make mechanisms work correctly.

This first Talgo trainset model has been the way to break trough into dynamic simulations using ADAMS Rail software and in our opinion a complete success for beginners.