NedTrain Consulting

Running dynamics of long passenger trains in push/pull operation

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Introduction

Long passenger trains are being used in pull operation all over the world for a very long time now. It has proven to be very useful and successful.
However one of the disadvantages of such a train combination occurs when reaching the end (last) station. The locomotive needs the be rearranged to the front of the train combination which leads to a certain loss of time and extra staff is needed to perform the rearranging.
In general it can be seen worldwide that the tendency with Railways over the years has moved to the use of long train combinations in pull as well as in push operation. Internationally long train combinations in push/pull operation are already being used successfully.

Up till now Dutch Railways (NS) only have been using trains with no more then 6 coaches and a locomotive in push/pull operation (short train). The use of longer train combinations in push/pull operation (up to 12 coaches) leads to a different running behaviour of the train compared to the use in pull operation, and therefore needs to be examined.

This paper describes the simulations of a long passenger train in push operation at different circumstances executed by NedTrain Consulting (NTC) of the Netherlands. The project was carried out for Dutch Railways (NS) and the objective of this study was to examine if any problems regarding safety standards would occur.

Procedure

The following steps were taken in the project:

- Determination of the most critical situations
- Performing real life measurements of a long passenger train combination in push/pull operation
- Study the data of the measurements
- Setting up an ADAMS/Rail simulation model of a long passenger train
- Validation of the simulation model
- Performing a simulation study with the model in push operation
- Study the outcome of the simulations

The different steps in the project will be discussed briefly.

Performing real life measurements of a long passenger train combination in push operation and study the results

Measurements are performed for the in advance determined critical situations. The measurements have the following results:

- the measured force levels are highest when running through double switches
- a long train combination (12 coaches pushed by a locomotive) exceeds the standard of Prud'Homme with respect to the lateral wheel / rail forces while running through double switches under full traction.
- the lateral wheel rail forces are exceeding the limits of the Prud'Homme standard with approximately 10%.
- a shorter train (6 coaches pushed by a locomotive) can run through the double switches under full traction without exceeding any safety standard.
- the lateral acceleration of the car body exceeds the UIC standard by approximately 30%

Setting up an Adams simulation model of a long passenger train

According to the results of the measurements it was desired to get more information regarding the wheel / rail forces and the lateral accelerations of the car body in different situations. Therefore the decision was made to built up a detailed ADAMS simulation model, so the investigation of the running dynamics could be expanded.

To shorten the simulation time of the runs the ADAMS model was limited to three highly detailed passenger coaches and one highly detailed locomotive.

The simulation model consists of the following parts:

- a locomotive equipped with a traction curve similar to a real life traction curve
- two complete passenger coaches with a detailed description of the bogies

- one detailed passenger coach equipped with an inertia force working at the front of the coach in the opposite direction of which the coach is running
- Buffer and draw gears between the different coaches

Locomotive

The locomotive in the simulation model is equipped with detailed bogies. Figure 1 shows the developed template of the bogie.

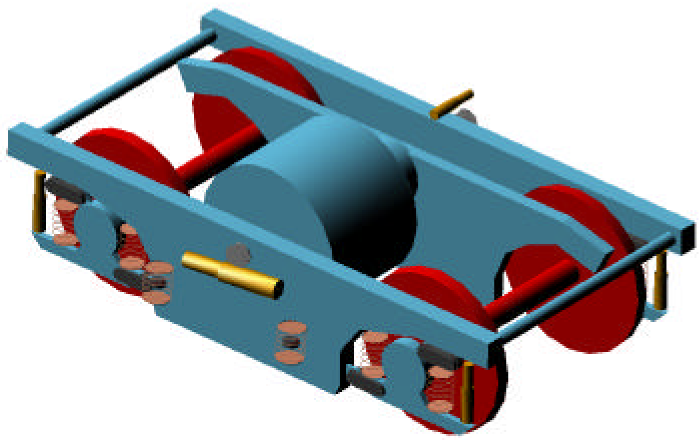

Figure 1: Detailed template of the locomotive bogie

The traction curve used in the model is similar to the real life locomotive traction curve. The amount of traction force during a run can be varied from zero traction to 100%.
Figure 2 shows the graph of the traction curve of the locomotive model.

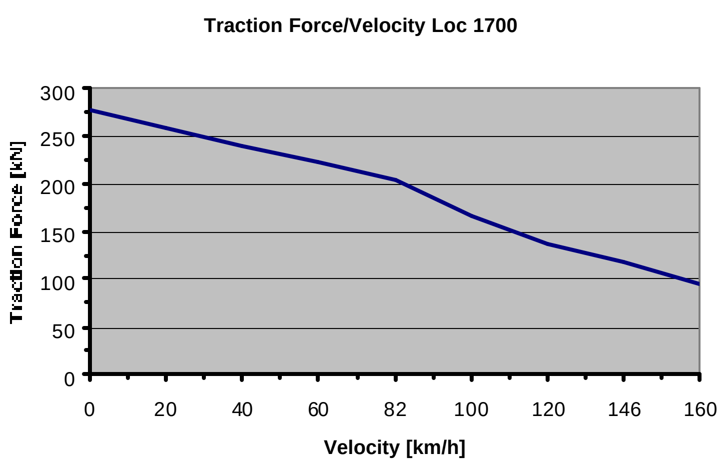

Figure 2: Total traction force of the locomotive at different velocities

Detailed passenger coaches

Like the locomotive bogies the three passenger coaches in the model are equipped with detailed bogies. This was done to get a response of the model as close to the response of a real life vehicle as possible. Figure 3 shows an example of a passenger coach bogie.

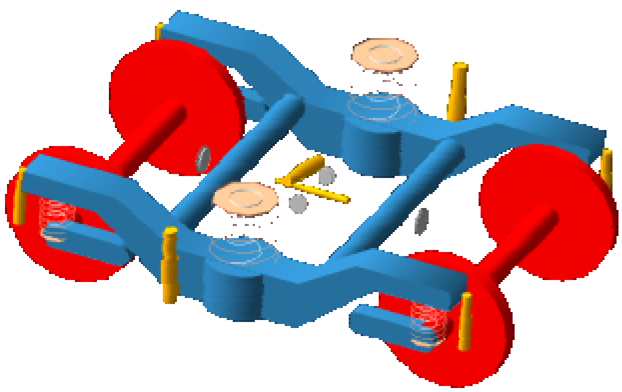

Figure 3: Passenger coach bogie (Y32)

Front car body

In order to keep the simulation time as low as possible, apart from the three detailed coaches in the model, the rest of the coaches in the long passenger train are simulated as an inertia force. This inertia force works on the front car body and varies according to the acceleration of the total train. Apart from the acceleration changes the force can also be varied by changing a parameter variable. This parameter variable stands for the number of coaches which are being pushed by the locomotive and the three detailed coaches.
Changing the train length or the number of passengers has a very big influence at the height of the longitudinal forces working between the different coaches. Higher longitudinal forces between the coaches leads to higher lateral wheel / rail forces.

Buffer and draw gears

As with real trains the simulation train model is also equipped with buffer and draw gears between the locomotive and the different coaches. The geometry and dimensions of the buffer plates in the model are comparable with the geometry of the plates used at real life ICR coaches (Intercity coaches) of NS. Figure 4 and 5 give a visualization and the basic layout of the ADAMS model of the developed buffer and draw gears.

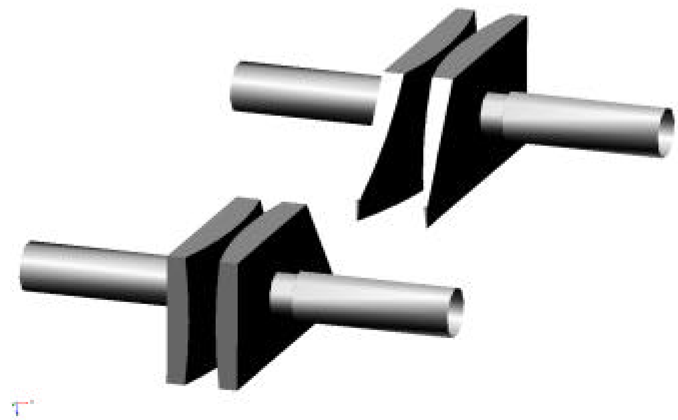

Figure 4: Visualization of the Buffer and Draw gear template

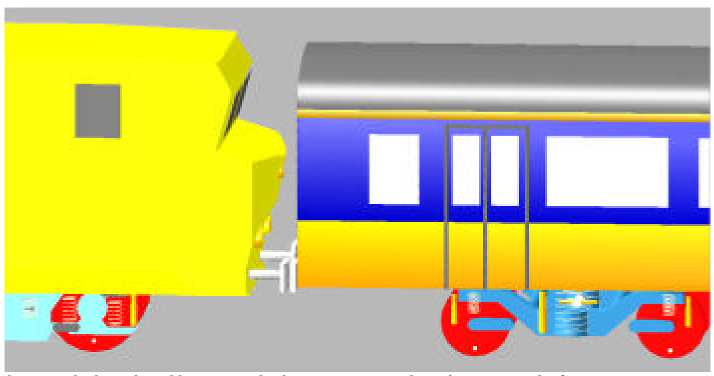

Figure 5: Placing of the buffer and draw gear in the model

The force splines of the spring/damper devices are built up according to the characteristics of the real life used devices. Figure 6 shows an example of such a force curve.

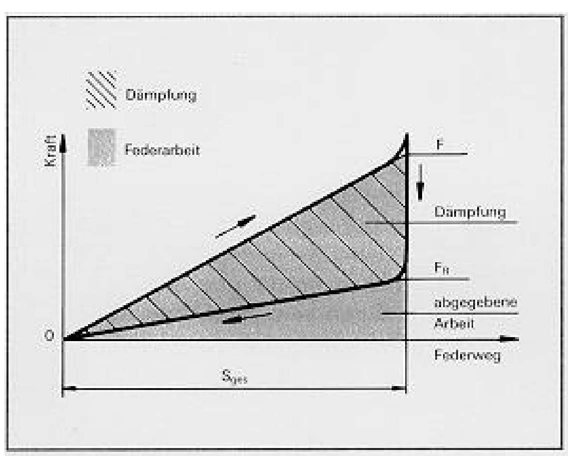

Figure 6: Real used vehicle force curve

The ADAMS model uses a solid to solid contact between two facing buffer plates. The spring/damper devices between a coach and the corresponding buffer plates

develop longitudinal forces as soon as the geometry of two facing buffer plates contact each other (when two coaches move relative to each other).
Figure 7 shows the layout of the model of the buffer and draw gear.

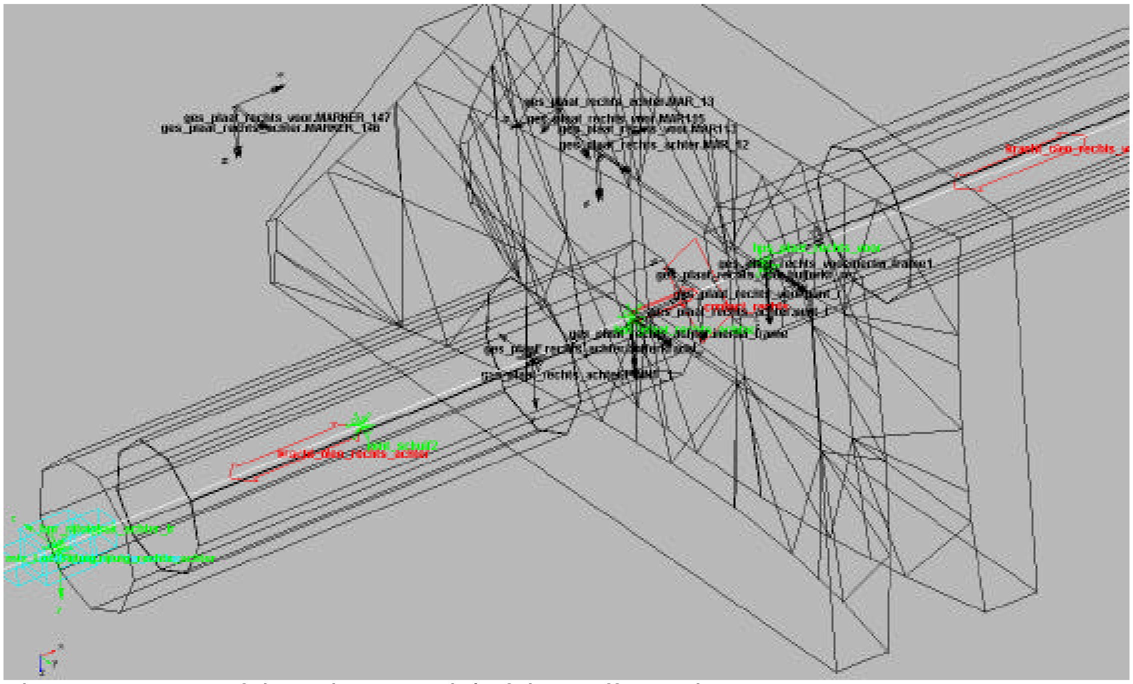

Figure 7: Layout of the Adams model of the Buffer and Draw Gear

In the ADAMS simulation model, the buffer and draw gear shifts between two different force splines dependent on the motion of the buffer gear.

The complete ADAMS model is shown in figure 8.

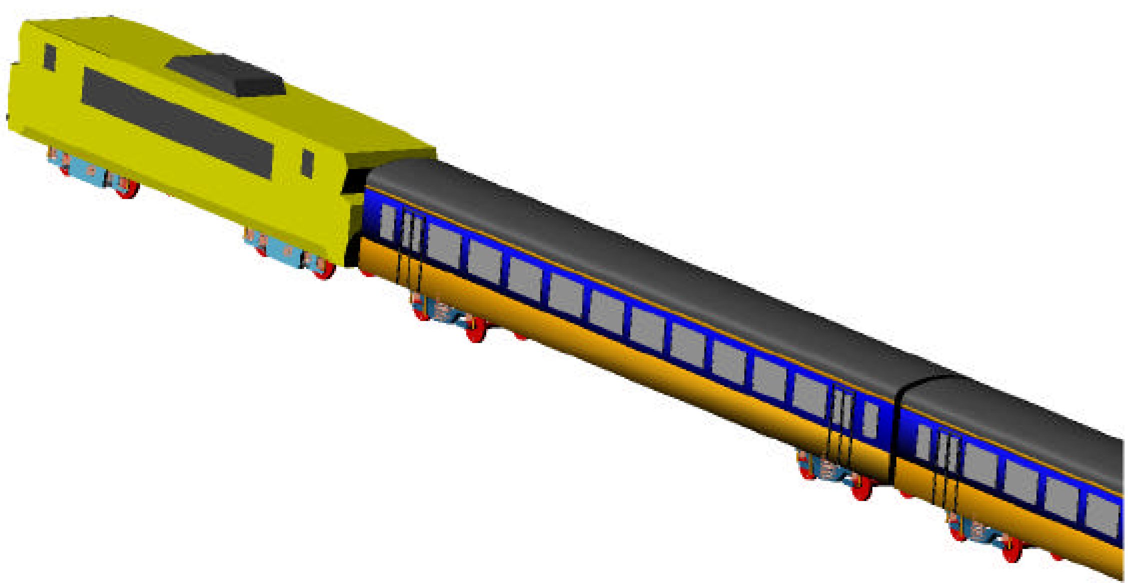

Figure 8: Complete simulation model

Validation of the simulation model

In order to assure that the simulation model has a vehicle response close to the response of a real vehicle, different validations are performed.
First of all each part of the model is validated separately by comparing calculated natural frequencies with real life frequency measurement values. In this way the linear behaviour of the model is examined.
Secondly the total model is validated by comparing certain calculated data with measured data by running the model through a double switch comparable with the double switch used for the real life measurements. In this way the non-linear behaviour of the complete model is examined.

An example of the comparison and validation of the linear behaviour of an ICR coach is given in table 1. The table shows the comparison between the calculated natural frequencies of the simulation model and the measured natural frequencies.

	Calculated natural frequencies of an ICR coach	Measured natural frequencies of an ICR coach
	[Hz]	[Hz]
f_{sway}	0.51	0,55
f_{swing}	1,45	1,50
f_{bounce}	1,06	1,10
f_{pitch}	1,26	1,25
f_{nose}	0,96	0,95

Table 1: Validation of the calculated natural frequencies (linear behaviour)

As can be seen in the table the natural frequencies of the simulation model are very close to measured ones.
In the same way as for the ICR coaches the natural frequencies of the locomotive are calculated and compared with the measured frequencies.

The buffer and draw gear model is validated by connecting one end of the spring devices to ground and the other end to a defined working force. By varying the preload of the working force, the movements of the different components of the model are checked and compared with the natural movement of real buffer and draw gear components. This visualisation check gives a good impression of the response of the model.
To ensure that the buffer and draw gear also works when placed between two coaches in the total model, the lateral and vertical movements are checked when running through double switches at full traction. The results of the movements are compared with the results obtained at the measurements.

Simulation results

The performed real life measurements learned that running with a long passenger train through double switches at full traction in push operation is the significant situation for this project to pay attention at.

In order to examine the running behaviour in double switches more closely, the first series of simulation runs pay close attention to the following points:

- influence of different loadings of the coaches (empty of maximum loaded)
- influence of the geometry of the track (different velocity double switches)

The simulation runs for a combination consisting of 12 coaches show that:

- maximum loaded coaches result in 5% higher lateral wheel / rail forces compared to empty coaches
- the wheel / rail forces are a little higher when running through low velocity double switches (1:8 for 30 km/h and 1:9 for 40 km/h) compared to higher velocity double switches (1:15 for 80 km/h)
- due to the high vertical forces resulting from the maximum loading of the coaches, the derailment quotient Y/Q is lower compared to the Y/Q under empty conditions
- Nadal's limit is not exceeded
- the first coach connected to the locomotive suffers the highest wheel / rail forces
- higher friction between the buffer and draw gears result in very high bump forces of the lateral curve dependent bump stops
- the Prud 'Homme standard is exceeded by 5% for a coach running with 40 km/h through the double switch
- the Prud 'Homme standard is exceeded by 30% for a coach running with higher velocity than 40 km/h through the double switch
- starting full traction before the complete vehicle has run through a double switch leads to high exceedings of the Prud 'Homme standard

Due to these results solutions need to be found to keep the wheel / rail forces below the Prud 'Homme values.
Therefore the points of attention for the second series of simulation runs are:

- change of the train length from 12 to 10, 8,and 6 coaches
- lower the percentage of traction produced by the locomotive (change from 100% to 80% or 60% for speeds below 40 km/h

The second series of runs have the following results:

- a decreasing number of coaches in push operation lead to lower wheel / rail forces
- the lateral accelerations of the coach in front of the locomotive exceed the UIC standard with approximately 30%
- up to a train length of eight coaches the wheel / rail forces remain below the Prud 'Homme standard
- by lowering the percentage of traction from 100% to 80-60% for a 12 coaches long combination the Prud 'Homme standard is no longer exceeded

Conclusions and customer advice

Based on the results of the measurements and the simulations of long passenger trains (12 coaches) running through double switches the following advice has been given to the customer:

- If it's preferred to start to give full traction before a complete vehicle has run through a double switch, keep the maximum number of coaches limited to eight
- Limit the amount of traction percentage to 60% for train speeds below 40 km/h
- Change the original geometry of the curve dependent bump stops of ICR coaches, so that the bump force comes in more softly
- Keep the friction between the buffer plates of the buffer and draw gear as low as possible

Value of the performed simulations

These days it's very expensive to set up real life measurements. For this project it was very useful to have a simulation model so that many different parameters could be changed very easily.
The simulation runs could be performed with different loadings, train lengths, traction percentage of the locomotive and different geometry of the track without any problems.