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# Estimation of the distribution of the wheel-rail friction coefficient in curves during the DYNOTRAIN project

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**ABSTRACT:** Among the experiment results of the DynoTRAIN project, the measurement of Y and Q forces in different curves have been corrected and used to extract a representative friction coefficient, by comparison to a model using Kalker's approach. The result is a set of friction values from 0.23 to 0.35 observed on field in conditions considered dry, and a standard deviation to a normal law of approximately 10 %.

## 1 BACKGROUND

In several procedures of the certification of new rail vehicles with respect to running characteristics (EN 14363 2005 and later), the wheel-rail friction has to be representative of dry weather conditions without man-made wheel-rail lubrication. But which values are really observed on tracks, to be used in simulations ? This was a task of the European research project DynoTRAIN.

In this project Petrov (2012) developed an algorithm on theoretical simulated results with Gensys, showing that it was possible to determine the friction coefficient when the forces are beginning to saturate. H. Chollet & E. Monteiro (in Zacher, 2012) tried to apply a similar principle to the DynoTRAIN measured data in curves. The risk of errors is coming from the measurement itself, but also from the vehicle model, whose representativity has been explored in another workgroup of the project (Vannuci, 2013).

## 2 METHODOLOGY

### 2.1 *The experiments*

During WP1 experiments, several bogies of the trains were interesting to estimate the local friction coefficient values. The measurement wheelsets of a relatively linear suspended locomotive, the BR120, were giving not only the Y and Q but also the Fx forces, and the passenger BIM coach wheelsets were equipped with yaw angle sensors.

### 2.2 *Iteration with simulations*

The measured Y Fx and Q forces of the locomotive are used as a first estimator of the T/N value, used as an input of a vehicle model, made by the VOCO multibody software. It includes a saturation of the contact, following Hertz and Kalker's theories, with a real time algorithm fitted on FASTSIM. A series of iteration, increasing or decreasing the T/N input ratio as a function of the  $F_{\text{measured}}/F_{\text{simulated}}$  ratio, will have a chance to converge to a small difference between these forces.

At the beginning it was planned to mix the use of two different vehicles but finally the initial iteration scheme (figure 1) has been simplified to a unique vehicle model.

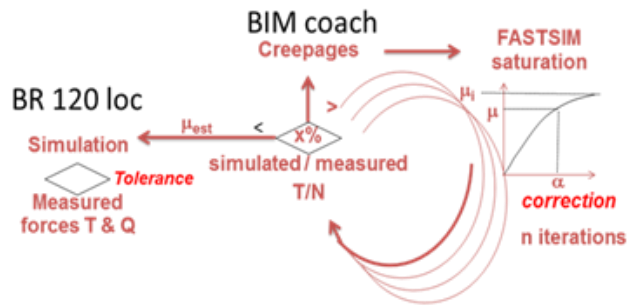


Figure 1. Initial iteration scheme

The iteration is not influenced only by the Y/Q ratio, but also by the T and N forces themselves thus by the suspensions characteristics and the center of gravity position. The analysis of the measurement led us to recalibrate frequently the Y and Q signals by considering firstly the straight line leading to an offset estimation, and secondly the constant curve leading to an eventual correction of the sensor gain (figure 2).

### 3 APPLICATION

#### 3.1 Experiments in Germany

The methodology has been tested in a procedure applied to the first experiments in Germany. Rail profiles have been considered as new and with an inclination of 1:40 while wheels have the theoretical S1002 profile. The first results were converging but were considered later inaccurate because the locomotive was used for traction, while this was difficult to simulate, without the track layout.

#### 3.2 Experiments without tractive efforts in France and Italia

In this second part of the campaign, the train was pulled with another locomotive and the BR 120 was unbraked and used without traction. The correspondence with the simulations is supposed to be better.

After the determination of the different offsets, the correction of the gains was applied on the curves of this sector. Figure 2 compares the lateral accelerations deduced from Y forces, deduced from the cant (DEV) and speed ( $V^2/R$ ) and the corrected Y function.

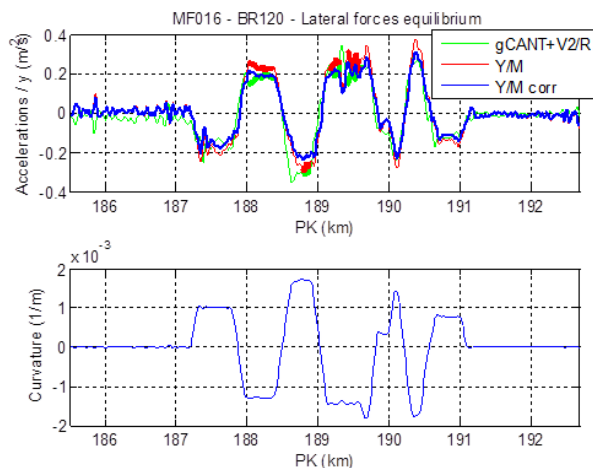


Figure 2. Gain correction on Y based on the lateral equilibrium, run#M16, BR 120

On the bottom of figure 2 (as on top of figures 3 and 5), is drawn the curvature  $1/R$ . The corrected signal is in bold line. The points on which the correction is based are in bold points on a

thin line. In this case, the gain on the Y measures at this place is proposed to be 0.82. A similar analysis is done on Q forces, section by section.

In term of friction coefficient, the values along the track are presented on figure 3.

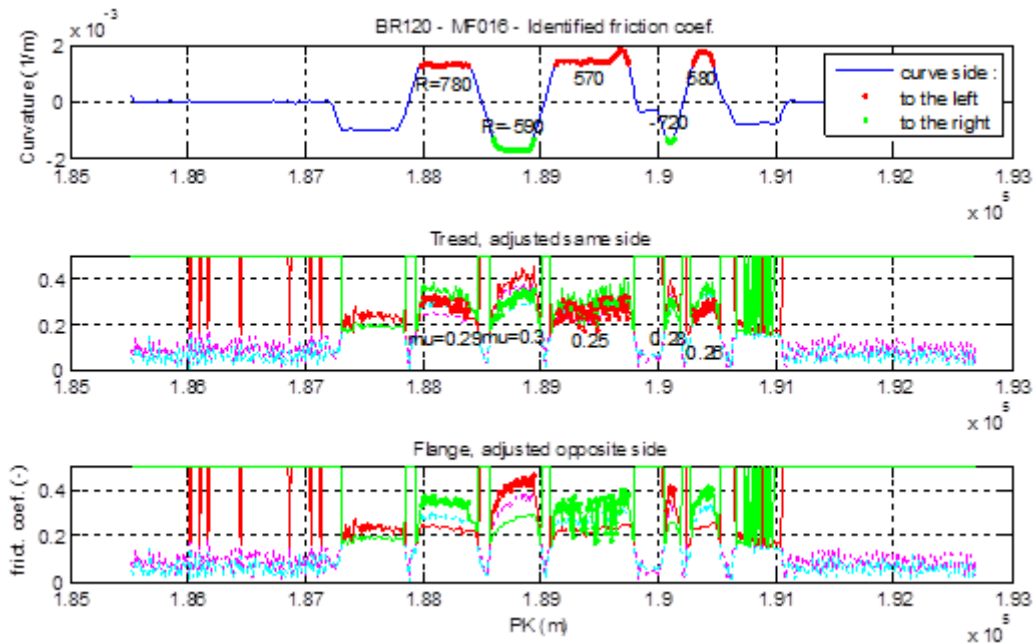


Figure 3. Measured T/N and simulated friction coefficient in several curves, run#M16, BR 120

Outside of the alternating right and left curves, the friction coefficient cant be estimated. In the 5 curves, the mean values are calculated for each curve : by example 0.29, 0.30, 0.25, 0.28, 0.25 on tread. Values are sometimes oscillating, by example in the R 570 m curve or in the last one just before PK 191.

A distribution of the friction coefficient can be done from the data spaced every 10 metres.

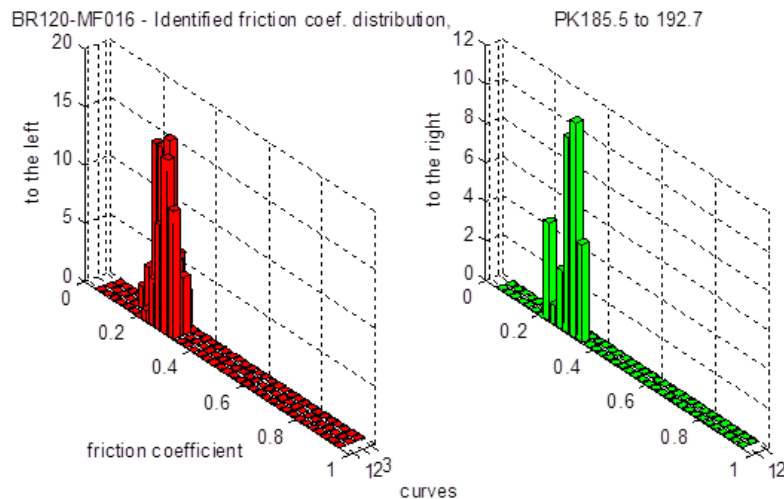


Figure 4. Distribution on the simulated friction coefficient  $\mu_{sim}$  in the 5 curves of figure 3

The result on figure 4 shows a mean value around 0.30, however the number of points is limited by the length of each curve, a longer one has been searched on the explored network.

A long loop in a tunnel in the mountain before Bourg Saint Maurice in the French alps has given an opportunity of a long quasi-static situation. The corrections have been applied on the offsets and not on the gains, giving a better confidence in results, like in the previous run.

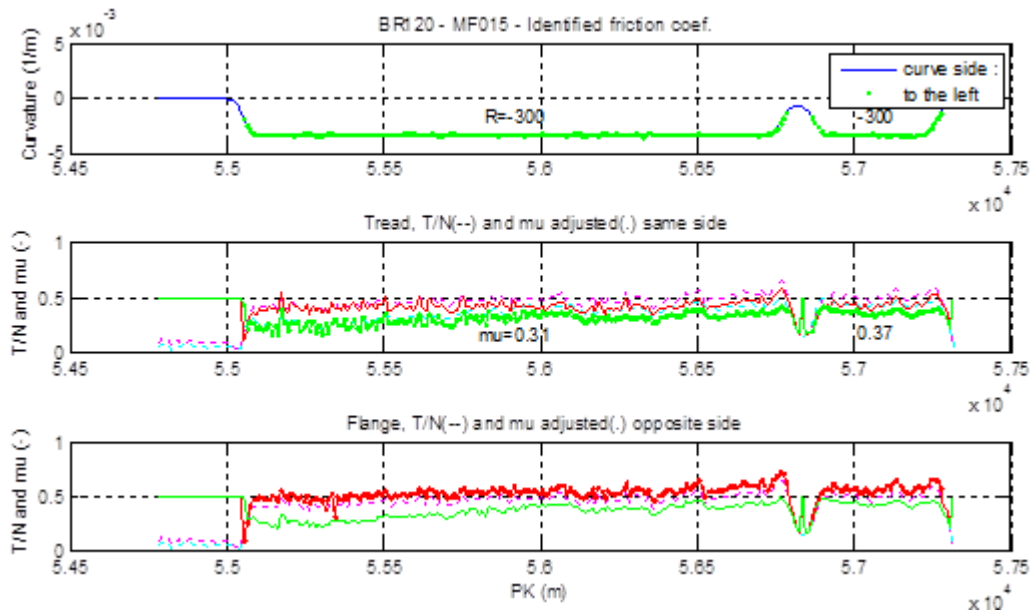


Figure 5 –  $\mu_{sim}$  and  $T/N_{measured}$  in a long curve, run #M14, BR 120

As the train was rolling always on the same side, the results are considered significant only on the left tread. The curve is separated in two by a small transition, this is why two columns are presented on figure 6 at left. The whole data are analysed on the right side of this figure, showing firstly a very good adequacy with a normal distribution :

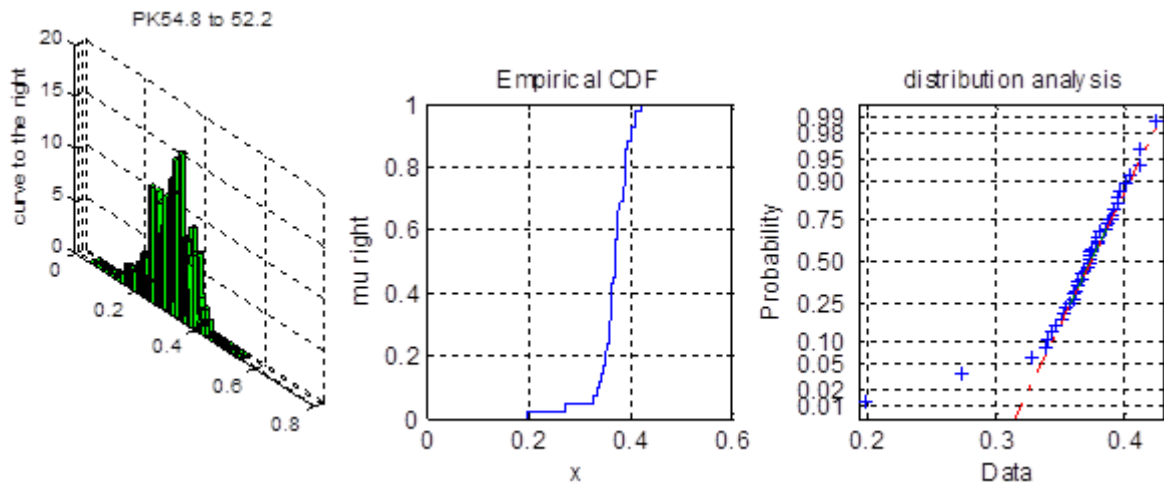


Figure 6 – Analysis of the distribution of  $\mu_{sim}$ , run #MF14, BR 120

The mean values and standard deviations in this case were, on the right tread, 0.37 and 0.037.

The spatial distribution presented in figure 5 is not strictly normal (figure 5); a slow evolution can be seen between the beginning of the curve at 0.23 and the end with a reached value over 0.40; the explanation can be a progressive cleaning of the wheel tread during this long curve.

A few points with low adhesion are outside the normal distribution (figure 6 right), but there are no local observation to estimate an eventual pollution by greased spots, by example.

### 3.3 Convergence analysis

The number of iterations is judged sufficient with 6 to 12 steps (figure 7). It is not recommended to increase this number; as the criteria is calculated on a mean deviation every 10 m, the result is stabilizing but sometimes diverging after 50 iterations.

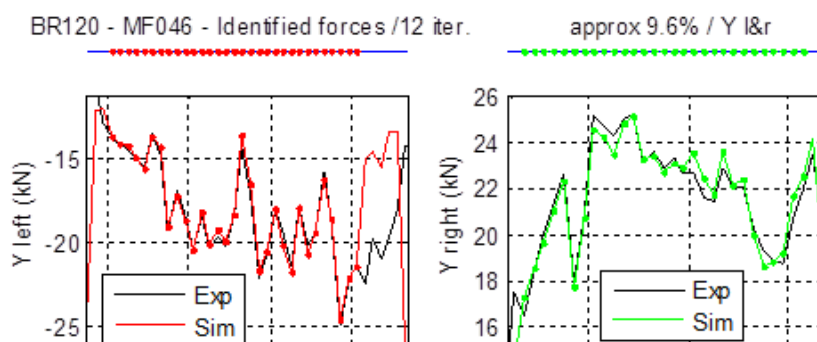


Figure 7. Convergence of the local left and right Y forces values in a curve along 400 m of track

After the iteration process, the local values of simulated Y forces (Sim on figure 7) are particularly well matching the experimental ones (Exp) on the left and right sides along 300 m in this curve. The results on flange are generally not converging so well.

#### 4 CONCLUSIONS

Two vehicle models, and a multibody software with a contact model using variable friction coefficient values on flanges and treads, have been used in order to compare experimental Y forces between measurements and simulations. A converging algorithm has been used. The converging observed criteria is the ratio between the measured and the simulated Y forces on the outer (attack) wheel of the first wheelset.

Some results, like generally the "very good" convergence of the criteria on Y, seems to provide very accurate and deterministic local values to the friction coefficient. However for the main used vehicle, a correction factor has to be applied to the mean measured Q and Y forces in order to match the  $Q_o$  forces (weight on each wheel, measured during static tests) and the lateral equilibrium in straight lines (mean Y value = 0). Some other limitations are observed :

- the roll equilibrium and the lateral acceleration in curves can sometimes be used to correct the gain on these forces, but it can be a compensation of model errors;
- the convergence process is too much influent on the flange friction coefficient values, sometimes diverging;
- the use of vehicles having dry friction dampers reduce the result accuracy.

In the best conditions, the traditional mean values between 0.23 and 0.37 have been obtained on tread, with standard deviations around 0.03 to 0.05 or 10 % of the mean value. This point is of interest as in the railway domain, it is often proposed to calculate the risk at 99.85 % by 3 sigma. But on the same time, the values obtained on flange are unreliable, with large observed variations.

#### 5 ACKNOWLEDGEMENT

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