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Priority 6

Sustainable Development, Global Change & Ecosystem

D2.1 – Load spectra for two service profiles to be used in new design concept of wheelset and in fracture mechanics analysis

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Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Introduction

Design of wheelsets has always relied on conventional contacts forces used in simulation. However, these loads are probably too conservative and hence prevent the developed wheels and axles to be optimized regarding engineering as well as economic factors.

Therefore, part of the WIDEM project was to measure these contact forces on two different railway vehicles: a tilting train in Czech Republic and a freight train in Sweden. These measurements were part of WP1.

The aim of WP2 was to analyse these contact by creating load spectra. The load spectra is a distribution of the number of wheel rotations that the wheel undergoes for different vertical/lateral load combination and is presented as a matrix of values where the vales are the wheels rotations and the indices correspond to vertical and lateral load level.

There is one load spectrum per wheel (right or left) and running condition: curves of different side, radius and cant deficiency; straight lines of different speeds; defects of different speeds.

This report details the software developed to detect the curves, straight lines and defects, classify the rolling conditions and compute the load spectra.

The obtained load spectra are then used for new wheelsets design.

2 Load extrapolation

Telemetry systems are very complex and delicate electronic devices. Thus, the use of such systems on railway wheelsets is very critical especially for inline tests. Therefore, it is not infrequent that spikes occur. Before being able to reconstruct wheel-rail contact forces it is necessary to filter out spikes and signal losses/noises.
For the purpose of filtering out spikes a very simple algorithm based on the gradient of strain gauge signal was adopted: whenever the gradient of the signal is higher than a given threshold (experimentally determined and a function of the sampling frequency and of the vehicle speed), the acquired sample at the corresponding time instant is substituted by the mean value of the previous and next sample. In fact, to be able to better smooth out spikes, a weighted mean between adjacent samples was implemented.
Once de-spiking has been carried out, the mean value of each bending deformation channel is eliminated. Note that, this operation is required due to the fact that zeroing of strain gauge bridges is carried out in a given angular position of the wheelset.
The resultant bending deformation (see D1.1) is then evaluated for each flexural bending measuring section. Such channels are thus analogically low-pass filtered with a Butterworth 6^{th} order low-pass filter having a cut-off frequency that may be varied from 0 to 50Hz (pass-band of the dynamometric wheelset).
Unfortunately, due to the fact that the bending deformation strain gauge bridges on the same measuring sections are not perfectly perpendicular one with respect to the other, even in case of constant contact forces the resultant bending deformation is oscillatory with multiple harmonics of that of the rotating wheelset. A digital filter has therefore

been developed. Note that the harmonics present in the resultant bending deformation due to the wheelset rotation are a function of the rotating speed of the wheelset itself. The time history of such bending deformations has therefore been cut into 10s long time intervals. The width of such slices is the best compromise between a time interval in which vehicle speed can be assumed as being constant (the smaller the slices the better) and a time interval that allows to evaluate the spectrum of the signal with reasonable frequency resolution (the wider the slices the better). For each time interval the spectrum (having a frequency resolution of 0.1Hz) of each resultant bending deformation signal is determined and the amplitude of the higher order harmonics is set to be equal to a weighted mean of the amplitude of adjacent frequencies. This procedure allows to effectively eliminate the noise introduced by non perfectly perpendicular measuring planes. The drawback of this digital filter is that the signal having frequency content exactly equal to that of higher order harmonics is distorted. To reduce this noise introduced by the filter, the width of the filtering window is kept as small as possible, i.e. equal to 0.8Hz around the higher order harmonics.

Finally, the procedure described in D1.1 to reconstruct wheel-rail contact forces is applied.

3 Curve detection

The gyroscope signal measured on the vehicle was chosen to detect the curves. As the raw signal is still very noisy (see Figure 1) and presents an offset, it needs to be cleaned (see Figure 2)

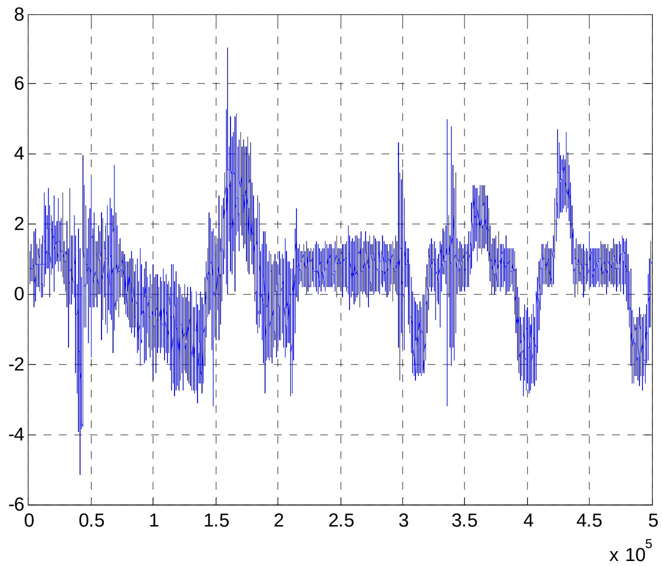


Figure 1: Raw gyroscope signal

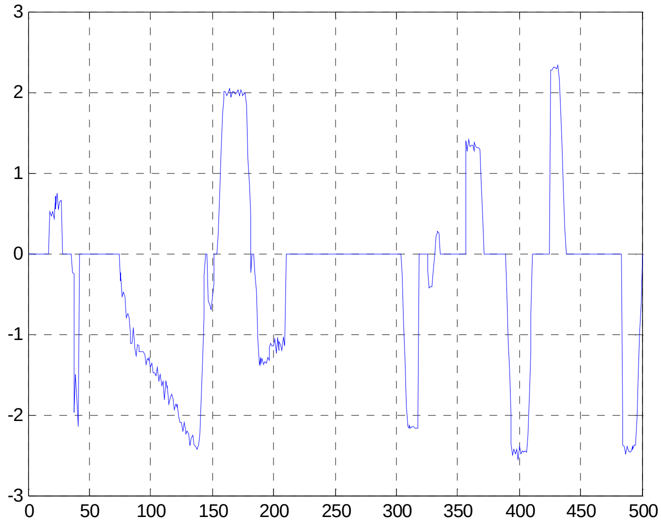


Figure 2: Gyroscope signal removed of its small peaks

To detect the curve, the gyroscope signal is swept. As soon as there is a time step where the gyroscope signal is different from zero, a flag is set to 1, meaning that we enter a curve. The time is saved as the begin time of the curve. The sweep continues and intermediate time are also saves for curve radius calculation. The end time of the curve is the time step where 1 of the 2 following conditions is satisfied:

- the gyroscope signal is zero;
- the sign of the gyroscope signal changes which means that we enter a curve in the other direction. The time step is than saved as the end time of the first curve and as the begin time of the next one.

The sweep continues until it reaches the end of the signal. The figure below (see Figure 3) displays some detected curves on part of the signal from the Pendolino. The begin time is marked by a green line and the end time is marked by a red line. The algorithm works properly.

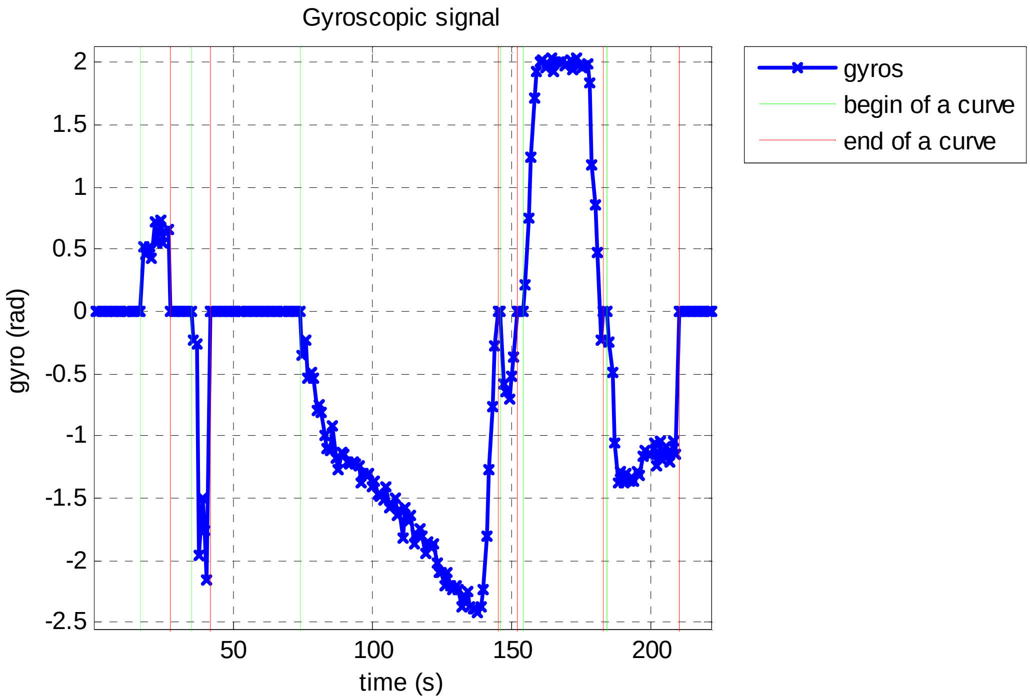


Figure 3: Curve detection

The detection of the straight lines is rather simple. When a curve begins, a straight line ends and when a curve ends, a straight line begins. Thus, when begin and end times of the curves are available, begin and end times of the straight lines are straightforward.

4 Classification

The classification of rolling conditions (curves, straight lines, defects) is done with 3 parameters for the curves:

- the gyroscope signal;
- the non-compensated acceleration;
- the curve radius.

The straight lines are classified according to the velocity. Defects are also classified according to the speed at which they occur. There is also a last type of event: errors in the load signal. Sometimes, the load signal is unrealistic probably because of a malfunction of a sensor.

Defects are identified by peaks in the signal of the vertical acceleration in the axlebox. The signal is thus swept and when the acceleration exceeds a given value, it is a defect. Begin time is set 2s before and end time 2s after.
These begin and end times are stored in the classification matrix according to the speed at which they occur. More details about this defects detection is present in D2.2.1.
These defects are events on there own. They thus cannot appear in other event classes. Part of the classification algorithm subsequently removes these timeframes from the curve's one.

After being clean off defects, the curves are classified according to the classes described here above.
First of all, the radius of each curve has to be calculated. The formula is:

$$\frac{Velocity\ (m/s)}{Gyro\ (rad/s)}$$

Therefore, the mean value of the velocity and the gyroscope signal are calculated between the 2 intermediate times coming from the curve detection.

As for the curves, the defects have to be withdrawn from the straight line too.
The straight lines are classified according to their velocity. However, it is not the mean value that is used here but the velocity is evaluated every time step and if the speed changes from class during a straight line, the latest is cut and classified into 2 different classes.

5 Load spectra

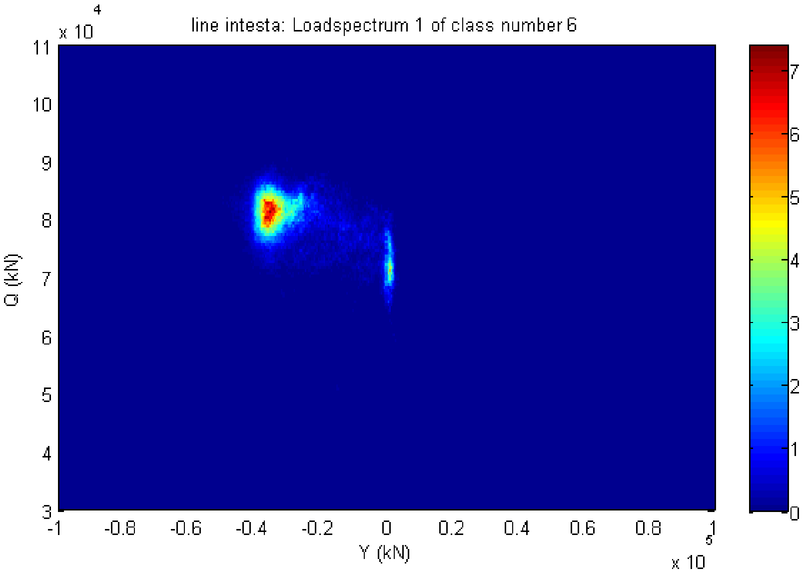
The load spectrum consists in a matrix where columns are discretisation of the normal contact force N (or Q) and rows are discretisation of the lateral contact force Y. The discretisation step is 0.5 kN.
However, the load signals coming from the Polimi routine have a precision up to 1e-4N. Therefore, the load signals have to be rounded at 0.5 kN. A sub-routine called “arrondi” does it.

A sweep of the normal and lateral load signals allows to count for each couple (Q; Y), the number of wheel turns subjected to this load combination with the formula:

$$\frac{v\,dt}{2\pi R}$$

where v is the velocity at time step t, dt is the time step (1 ms) and R is the wheel radius.

These matrices can be plotted. Figure 4 is an example of a load spectrum for the Pendolino train for a right curve. Figure 5 is an example of load spectra for straight line.
This figure shows that up to 7 wheel turns are subjected to a load combination of 80-85 kN for the normal load and 40 kN for the lateral load on the outer wheel and a load combination of 60-65 kN for the normal load and 15-20 kN for the lateral load on the inner wheel.



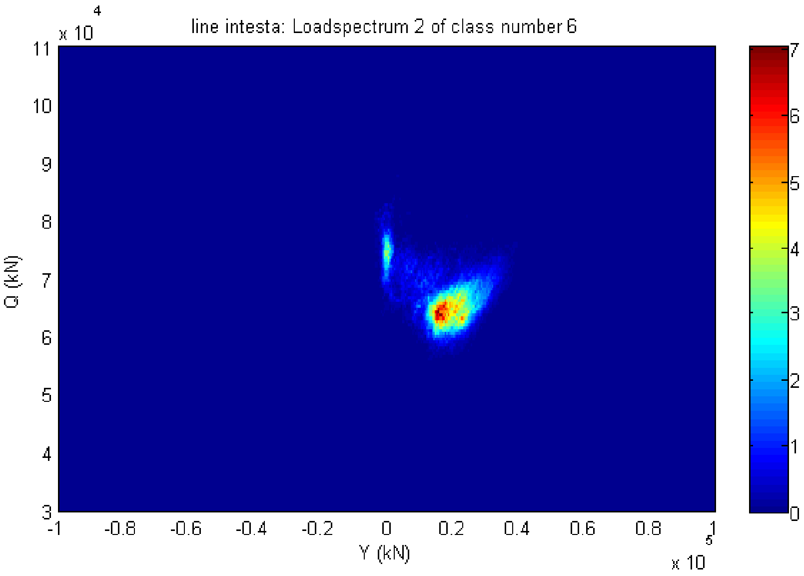
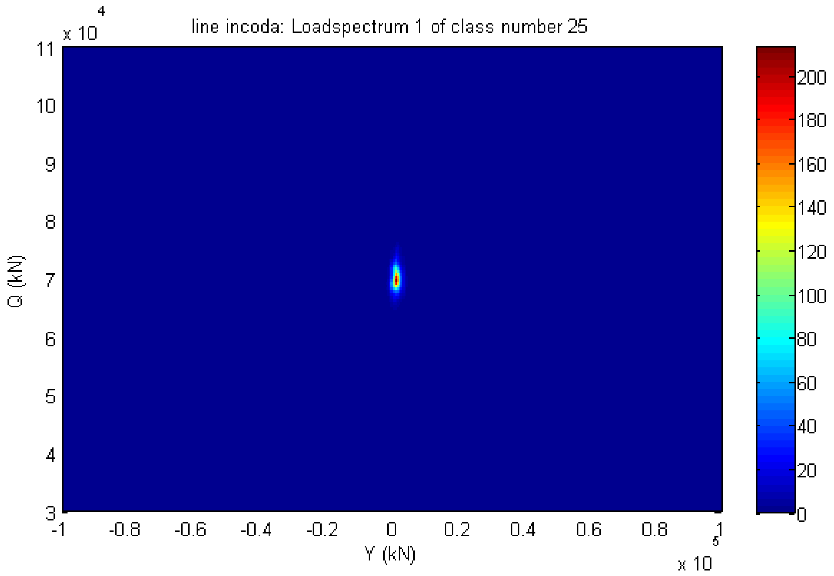


Figure 4: Load spectrum for the Pendolino train (class number 6)



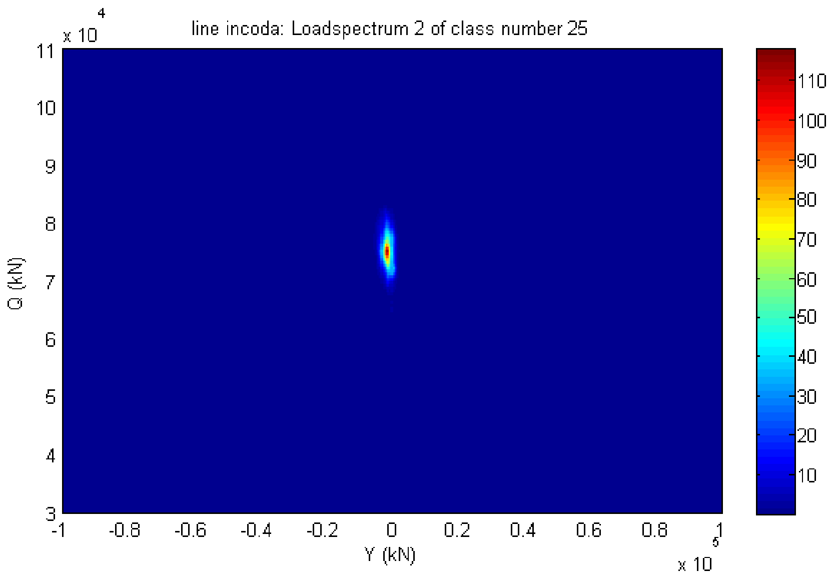


Figure 5: Load spectra for class n°25 of Pendolino (rear bogie instrumented)

6 Time histories

Time histories are matrices where the columns stand for the time and each row stands for a particular signal:

1. N1 (or Q1): normal load on wheel 1 (N);
2. Y1: lateral load on wheel 1 (N);
3. N2 (or Q2): normal load on wheel 2 (N);
4. Y2: lateral load on wheel 2 (N);
5. X1: longitudinal load on wheel 1 (N);
6. G: gyroscope signal (rad/s);
7. NCA: non-compensated acceleration signal (m/s^2);
8. VA: vertical acceleration of the axle box signal (m/s^2);
9. LA: lateral acceleration of the axle box signal (m/s^2);
10. v: velocity (km/h);

For class number n, the classification matrix of each file is swept along the row number n. Parts of the signals here above selected between begin and end times contained in that row are stored in the time histories matrix.

7 Conclusion

Software has been developed by D2S and it is able to detect curves from gyroscope time signals. It can also calculate the curve radius from the yaw speed and the running speed and classify the curves according to there radius, non-compensated acceleration and direction. According to this classification, the software can select the correct time frames in the load signals and count the wheel rotations submitted to a given combination of normal and lateral load. This leads to load spectra. These load spectra are then used in the design of new wheelsets.

Measurements on two lines, a Pendolino high speed train in Czech Republic and a freight low speed train in Sweden. The results for the Pendolino are good and coherent. For the freight train, results are more difficult to analyse, especially when the train is empty.

Load spectra and load time histories are finally available for both vehicles in every running condition and these load spectra can be used in wheelsets design.