RAILCOM

Final Reporting Interactive Conference

Electromagnetic compatibility at train-track interface - low frequency domain

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Train-track interface – low frequency domain

- Low frequency – up to 20 kHz
- RAILCOM space for low frequency domain – WP2
- WP2 = Compatibility between vehicles and track circuits
- Main objectives:
  - Provide a set of fully validated characteristics and technically sound testing methods and approaches to achieve and demonstrate electromagnetic compatibility between vehicles and track circuits for future interoperable lines
  - The specification and methods shall become generally accepted and recommended tools for the design and acceptance processes (European Standards)

Main solved tasks I

- ❑ **Inventory of possible interference mechanisms influencing track circuits**
- ❑ **Selection of the knowledge gaps to be solved in relation to future harmonisation:**
  - o **Focus on a harmonised rolling stock test method**

  Remark – CENELEC WGA4-2 selection of a list of existing track circuits intended to be used as interoperable including their limits defined pursuant to existing national rules and methods

  - o **Inputs necessary to cover knowledge gaps related to the vehicle test method and further EMC aspects have been discussed with CENELEC WGA4-2 (inputs to pr15360/EN 50238-2)**

Main solved tasks II

- **Selected knowledge gaps:**
  - **Characterisation of interoperable test infrastructure**
  - **Summation rules**
  - **Transient effects influencing track circuits**
  - **Time vs. frequency domain analyses**

Main solved tasks III

- Proposal of the structure of the unified test methods for vehicles
- Selection of suitable vehicle and network configurations for tests to cover knowledge gaps related to characterisation of interoperable test infrastructure
- Analyses and evaluation of data recorded during the test campaigns
- Specification of the proposals of the unified test methods for vehicles – inputs to pr15360/EN 50238-2

Characterisation of interoperable test infrastructure I

- Requirements to the compatibility test infrastructure are not harmonised in Europe
- Main goal – simplification of vehicle compatibility measurements. Compatibility test infrastructure characteristics have to be known and defined well
- Measurements should be done only once per power supply system

Characterisation of interoperable test infrastructure II

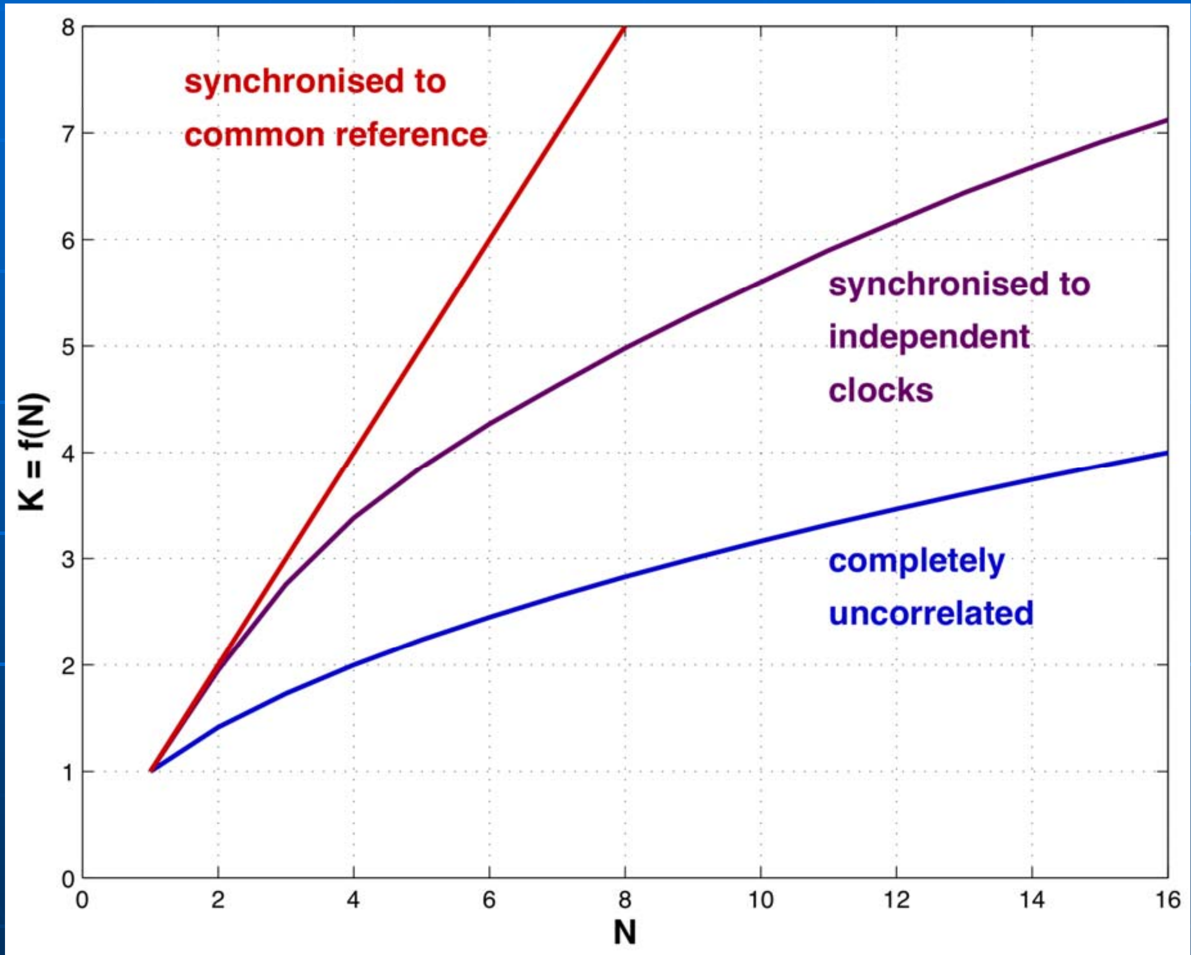
- Important parts (seen from the train) in the characterisation of the infrastructure:
  - Source voltage versus frequency
  - Impedance versus frequency
- Theoretical system analysis
- Test campaigns:
  - Verification of theoretical results
  - Identification of source voltage in different networks (i.e. mainly influence of other trains)

Summation rules I

- **Multiple sources (N) in one train:**

Synchronised to common reference	Synchronised to independent clocks	Completely uncorrelated
K=N	K = f(N)	K = √N
Synchronisation to ▪ Line frequency ▪ Common internal clock Examples: ▪ Harmonics from substation ▪ Steps in line voltage ▪ Non-interlaced PWM harmonics synchronous to AC line voltage	Synchronisation to ▪ Independent clocks ▪ Motor angular position Examples: ▪ Harmonics from fixed frequency PWM ▪ Motor inverter harmonics with phase depending on the motor angular position only	No synchronisation at all Examples: ▪ High order harmonics, depending on converter parameters ▪ Interference from pantograph bounces, neutral sections, gaps

Summation rules II



- **Table and figure – valid for PWM converters**
- **UIC550 – valid for harmonics generated by diode and phase angle controlled converters**

Transient effects influencing track circuits

- **Include both slow and rapid changes of operation points of a device and the corresponding shape of a signal, e.g. the return current of a train**
- **The full signal processing method can be defined as:**
  - **In time domain: filter function, plus averaging method and time window**
  - **In frequency domain: window length and overlap time, windowing function, frequency resolution filter function (or number of lines) to build RMS value of the signal**

Remark - If one of these parameters is not clearly defined, results of an interference current evaluation are unclear and may vary from application to application

Time vs. frequency domain analyses

- Requirement to deal with both steady state and transient behaviour
- Methods available:
  - Time domain analyses – track circuit centre frequencies, current limit at the centre frequency which also encompasses currents at all influencing frequencies within the bandwidth of the filter using RMS technique, filter curve and integration time have to be known
  - Frequency domain analyses – used for existing and new audio frequency track circuits with an integration time of 0.5 seconds

Track circuits test signals I

- To confirm and prove compatibility of track circuits and railway vehicles a set of typical test signals has been proposed
- These test signals are intended to be used for (future) interoperable track circuits first of all
- Demonstration of immunity of track circuits against transients

Track circuits test signals II

- Test of steady state behaviour against the whole frequency range between supply frequency and 20 kHz, to check the validity of the filter curve
- Test of transient behaviour with typical waveforms of the return current of a train:
  - Filter pre-charging current
  - Transformer inrush current
  - Ramp up of traction power
  - Loss of load
  - Sinus of variable frequency

Unified test methods for vehicles I

- Influencing units – configurations under which the train has to be measured:
  - Completely switched off (reference measurement)
  - Auxiliaries only
  - Auxiliaries plus train busbar
  - Traction in normal configuration, no train busbar
  - Traction in normal configuration plus train busbar
  - All credible degraded modes (e.g. one bogie out of operation) which might occur during operation
  - Faults inside the influencing unit and corresponding effects are not within the scope of this specification

Unified test methods for vehicles II

- **Operating conditions for measurements:**
  - **Start-up and switching off of vehicle at standstill**
  - **Running through neutral sections (AC) or gaps (DC)**
  - **Acceleration / braking at 100 % and 50 % of available tractive effort / power limitation**
  - **Conditions with worst case interference generation shall be included in these test cycles**
  - **Abrupt changes of tractive / braking effort, both operated manually and by automatic speed control (if applicable)**
  - **Coasting at different speeds**
  - **Acceleration and braking (100 %) under bad adhesion**

Unified test methods for vehicles III

- **Effects of current collector bounces**
- **All above cycles in the form of short test runs. Each cycle shall be carried out three times to give confidence that the results are reproducible**

❑ Infrastructure requirements for measurements:

- **Verification measurements for characterisation to be done on a test track as pre-test for operation in normal network; therefore, conditions on infrastructure side must be known and controlled, but a fully closed line section is not mandatory**
- **Infrastructure requirements for avoidance of duplication of tests in different countries**

Unified test methods for vehicles IV

- **Test setup for measurements (hardware):**
  - **Separate current sensor at common feeding point (pantograph) for all on-board equipment of one influencing unit**
  - **Anti aliasing filter**
  - **Digital recording device (DAT recorder, PC based or other electronic equipment); extraction of selected parts of a test run and conversion to digital data files in a widely used format (ASCII, Matlab, ...) must be possible easily**
  - **Resolution of A/D conversion at least 16 bit, with the target of 24 bit (depending on interference limit to fundamental current ratio)**
  - **Accuracy of the whole chain (with respect to individual limits) 5 % or better**

Unified test methods for vehicles V

- Useful frequency 20 kHz, i.e. sampling rate ≥ 48 kHz for the current channel. Higher useful frequencies may be required in some countries if corresponding trackside equipment exists
- Additional recording of vehicle status and location (speed, tractive effort, line voltage fundamental, kilometrage etc.), with an adequate (eventually lower) time resolution, but easy link to current signal must be possible during measurement and for post processing and evaluation
- Verification of the measurement chain in the train under test required prior to the measurements

Unified test methods for vehicles VI

- **Evaluation method:**
  - Time domain analysis and FFT
  - FFT – On-line visualisation of spectrum, on-line comparison with gabarit
  - Detailed evaluation of compatibility with each track circuit channel in time domain except FFT for DC or AC 50 Hz supply & track circuit response time ≥ 500 ms
  - Compatibility is reached if the limit is never exceeded for longer time than specified for the corresponding track circuit
  - In case of non-compatibility: the time spans where the limit is exceeded will be analysed using the spectrum (FFT), which shall show the cause of the exceedance
  - All evaluation is done digitally

Unified test methods for vehicles VII

- **Documentation:**
  - The measured data shall be stored in an easily accessible, digital format or must be convertible easily for further evaluation also once the tests have been completed and the vehicle is accepted
  - Overall schematics diagram (traction and auxiliaries)
  - Main parameters of the power circuits and converters
  - Description of test equipment used
  - Definition of infrastructure on which the tests were performed
  - Description of test conditions (load, travelling direction, weather, etc.)

Unified test methods for vehicles VIII

- One typical steady state spectrum for each configuration with indication of the corresponding operation point
- Peak hold spectrum per test cycle (excluding major transients)
- Speed, tractive effort and line voltage as well as time domain results for each track circuit channel (output of evaluation method as defined above) versus time for each test cycle

Test campaign

- Characterisation of the infrastructure – several railway infrastructures within Europe with respect to the source voltage versus frequency by registration of the catenary voltages
- Measurements and further data evaluation:
  - Test campaigns in several European countries – Germany, Switzerland, France, Poland, data from Italy
  - Test conditions – different railway vehicles (ICE, Re 460, TGV, E 499.3), different infrastructure conditions (low/high traffic density, close/far from substations)
  - A PC based autonomous data-acquisition system
  - Data evaluation – based on time domain analyses and bandpass filtering

Further steps?

- Reasonable frequency management between track circuits and railway vehicles (as a long-term future idea) – possibility to reduce number of track circuit types used for interoperable lines → available frequency bands for the traction units could be extended
- Harmonisation of national differences in definition of basic requirements and conditions of track circuit parameters – this step would allow to define track circuits limits on the same bases and, subsequently, have the harmonised European track circuits limits for given track circuit classes

End of presentation

Thank you for your kind attention