Mobile measurement system to analyse vehicle-generated magnetic fields

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Operating modern rail vehicles running on railway lines while complying with all safety requirements is not as easily done as one may expect considering that standard gauge is used. Many, in part country-specific, requirements and limitations need to be met to demonstrate the absence of electrical and electromagnetic interaction between vehicles and infrastructure. All this for but one reason: To ensure safe and highly available operation of the overall "railway" system. If, in future, these conditions are to be met across borders, that is, systems are to be interoperable, then demand will not stop at non-reactive vehicle and control technologies, but will require internationally standardised evaluation and measurement methods, because only these will allow transnational vehicle certification.

The sum of the measures necessary to achieve absence of interaction between vehicles and infrastructures is covered under the term EMC (ElectroMagnetic Compatibility). However, knowledge of the immunity of the infrastructure is not the only prerequisite for the evaluation of interference limits. There are, as well, interference data for rolling stock that need to be determined with precision, to allow comparison, and to be reproducible. To this end, the EN50238 technical appendices call for measurement and evaluation procedures capable of making this possible. The so-called frequency management will be defined in the "Interface Document" of the current revised TSI CCS, on the basis of the procedures set forth in TS50238-3 [2]. Uniform and reproducible measurement, evaluation, and standardised measurement conditions are the cornerstones for the measuring array defined in TS50238-3. Measurement series carried out in cooperation between Austrian Federal Railways (ÖBB) and Frauscher Sensortechnik GmbH confirmed that the "Magnetic Noise Receiver – MNR" measuring system by Frauscher is capable of complying in full with the requirements of TS50238-3 with regard to measurement and evaluation methodology (Figure 1).

1 Basic principles

Operating a railway system requires a large amount of technical equipment in the track area. This equipment interacts with the vehicle, so that the operation of electrical and even diesel-powered vehicles may cause interferences that may affect the general infrastructures, including cable systems. When a vehicle complies with all requirements regarding interference emissions, it is deemed non-

Figure1: Frauscher Magnetic Noise Receiver for standardised magnetic field detection

reactive and certified for operation. Negative effects affecting, in particular, signalling systems are to be ruled out in this case.

Safety installations have to perform tasks that are safety relevant because they are vital for operations: unpredictable external interference may, in extreme cases, lead to safety critical states. Usually the interference distorts the evaluation criteria of a safety installation or simulation of switching criteria due to inductive interference. These include untimely reset commands for railway crossings, and false messages regarding status monitoring of light signals or turnouts. Even installations that are not vital for operation (data transmission, communications) may suffer from interference as their failure or disruption has a negative impact on overall availability and punctuality, even if it does not affect operational safety.

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2 Interference magnitudes

Along electrified railway lines interferences are caused by traction power in fundamental frequency and several harmonics, depending on the drive technology and the onboard control and transformer equipment of the vehicle. Even modern diesel-powered trains may generate noise spectra this way, which is why these vehicles also need to be considered.

The major interference magnitudes are as follows:

- Galvanic (= conductive) coupling, even single-pole
- Capacitive coupling, i.e. forming of an electric field
- Inductive coupling, i.e. emission of an electromagnetic field

The influence of these interference magnitudes is either localised – sporadic interference – or, because the interference magnitude accompanies the return current, causes linear interference.

There are a sufficient number of methods to measure electrical interferences or disturbances caused by faulty galvanic coupling (among others, symmetry measurements, ground fault or fault resistance). Experience shows that interferences in fundamental frequency (16.7 Hz, 50 Hz) are quite easy to control or compensate. Radiated magnetic fields of higher frequencies, which due to the interference behaviour are not so easy to determine in terms of source, spectrum composition or results, are far more difficult to handle. Vehicle-related causes vary:

- Interfering magnetic fields only occur under certain load conditions (upward runs, braking, double traction, ...)
- Interference fields are high-frequency fields with a rather a short range
- Interference fields feature the resonance frequency or an effective interference frequency of the equipment exposed to them
- Interference fields only occur in certain components of the vehicle.

In any of these cases, location of the interference source will only be possible using an antenna system. If, for the sake of comparability, quantization is applied, the system needs to be a standardised system, as described, for instance, in TS50238-3, version 2010.

3 Railway related conditions

As mentioned above, certain equipment or entire cable systems installed in the track may be exposed to the influence of interference fields. In practice the interference across larger distances (i.e. “longitudinal interference sources”) is only relevant for low frequencies. However, it is not possible to evaluate them using antenna systems as such interference is normally injected with traction current and propagated through cables and rails. The contrary applies to high-frequency interferences: Their rail-based propagation is only relevant in the proximity of the vehicle, as damping increases as frequency increases.

3.1. Sporadic interferences

In terms of the infrastructure side it is mainly installations installed close to the track that are exposed to interference by higher-frequency magnetic fields. This is due, on one hand, to the near-field behaviour of high-frequency interference sources and, on the other hand, to the fact that many of these installations are based on operating principles generating electromagnetic fields.

3.2 Longitudinal interference

As stated above, higher frequencies do not significantly impact longitudinal interference in far-field behaviour. However, due to a rail contact installed next to the rail, the high-frequency interference current injected with return current works directly under the vehicle; i.e. directly under a conducting wheel these current harmonics may be very large and could be induced, in the wheel-rail current path, directly into trackside equipment and installations.

4 Measures to be taken for vehicles

Modern vehicles allow effective measures to prevent or attenuate higher-frequency noise spectra. Screening, filtering or selective damping are options that protect against high frequencies. Free design of control frequencies of the vehicle’s traction system and hence shifting vehicle noise spectra to frequency bands that do not affect infrastructures is one approach to solve the problem. It requires detailed knowledge of the interference behaviour of trackside equipment such as rail contacts, axle counters or track circuits. Country-specific operating, interference and threshold frequencies of trackside equipment have to be known. This also explains why a comprehensive solution as a basic condition for interoperability is not easy to find. In some countries certain frequency bands do not lie within the noise spectrum of the installations deployed, and therefore frequencies within these ranges are of no interest to the national certification boards and, hence, are usually not subject to evaluation. There may be serious implications for cross-border traffic if these non-evaluated frequency bands are part of an effective noise spectrum in another country. One of the measures for vehicles in cross-border traffic is, therefore, the use of control software, which generates other pulse frequencies and thus different harmonics (software switching at borders!).

5 Threshold values for magnetic fields over frequency range

Within the scope of the new version of TS50238-2 [1] and TS50238-3, member states and their representatives carried out a survey to determine, among other things, what type of track equipment (axle counters, track circuits) is used with what type of systems, frequencies and current injections (age, quantities deployed) in each national territory. The survey distinguished whether and how many were older installations, which

Figure 2: MNR antenna system with recorder and monitors

could still be deployed in large quantities regionally, or whether they are systems to be preferred in future for new or modernization projects. System components scheduled for renewal were excluded: They are not to be used for new projects and, at best, could be kept for spare parts. The data of all internationally disclosed sensors to be deployed in future on interoperable lines thus provide a frequency envelope for each spatial axis representing the levels below which vehicle interference spectra have no effect. These curves in combination with the list of "Preferred Axle Counters" are described in TS50238-3 as a prerequisite for interoperability of vehicles and axle counting sensors.

The Technical Specification defines the nature and extent of acceptance runs for a vehicle to be certified. To this end vehicles have to travel over a predefined measuring antenna system. The precise antenna requirements are also defined in TS50238-3. The thresholds specified must not be exceeded in the different operating modes of a vehicle. Thus, measurement of the radiated electromagnetic fields will suffice to demonstrate a vehicle's compatibility with axle counter systems. As thresholds to be compared are based on the measurement limits of the systems preferentially deployed in Europe, cross-acceptance can be demonstrated under uniform conditions.

The working frequencies of the different wheel sensors deployed and their different frequency ranges result in the following diagram (Figure 3).

The two new parts of EN50238 technical appendices will at first be published as a Technical Specification, because the measurement methods for electromagnetic susceptibility still need to be tried and tested in the field, and the type and extent of acceptance runs may still be adjusted. Thus, the relevant provisions in the TS can be adapted quickly in line with practical experience. In the medium term it is planned to also include these parts in a European standard.

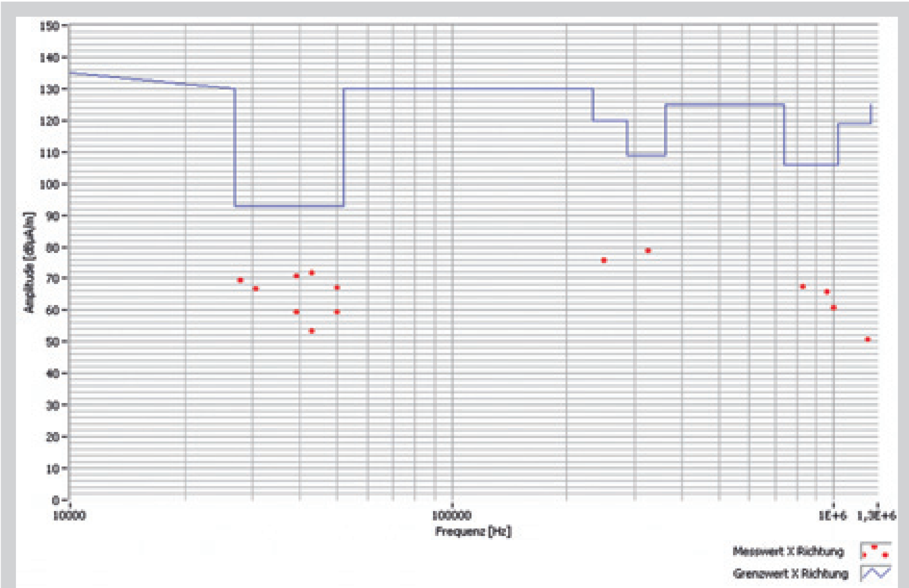

Figure 3: MNR real-time evaluation in compliance with TS50238-3

6 Challenges in the development of the measurement system MNR

Frauscher Sensortechnik GmbH has been working for some time on the development of an appropriate measuring device from a purely theoretical point of view. These theoretical approaches were tested and confirmed in several practical laboratory trials. Inquiries from ÖBB Traktion GmbH (today: ÖBB-Produktion GmbH) / Maschinentechnische Messgruppe), led Frauscher to the idea of combining the experience gathered in a measurement system. ÖBB Messgruppe and Frauscher discussed many issues related to the practical measuring process and to the requirements for a practical measurement method to record and evaluate magnetic field interference. Based on the experience in the field of sensor technology, Frauscher developed the Magnetic Noise Receiver (MNR) measurement system, which offers the following functionalities:

- 3D acquisition of measuring fields in a single measuring run
- Real-time evaluation of measuring data in compliance with TS50238-3 version 2010 and comparison with admissible thresholds defined therein
- Real-time evaluation of measuring data using FFT analysis
- Recording of traversing speed and timestamp
- Automatic start and stop of measurements
- Guaranteed deviation of < 1.5 dB

- Frequency range from 10 kHz to 1.3 MHz
- Recording of measured raw data
- Easy installation and configuration of measuring array
- Fast commissioning, meaning that time at rail is short
- Resistance against common stress loads at rail

Based on the jointly specified product requirements, the first MNR prototype was built. Initial laboratory tests faced the problem that there was no adequate noise spectrum available to test the MNR under laboratory conditions. Therefore, using a Helmholtz coil as homogeneous transmitting antenna, an interference field was generated as measurement standard and fed into the measuring antenna system. This field was measured with a calibrated probe and then measured again with the MNR to determine the differences between the calibrated probe and MNR. After respective adjustments and calibrations of the measuring amplifier in the MNR, the time had come to carry out first measurements on a vehicle in cooperation with ÖBB Messgruppe.

So as to provide the required linearity of the measuring results, the MNR had to be optimised for the lower (10kHz – 100kHz) and the higher (100 kHz – 1.3 MHz) frequency ranges. Two separate antennas were developed for these two frequency ranges. Both MNR probes (MNR-LF and MNR-HF) feature three antenna coils each for the three spatial axes.

In addition to the detection coils, the electronics necessary to linearise the frequency response are integrated in the probe. This allows measuring results with amplitude deviations of <1.5 dB. The preamplifier, also integrated in the MNR, featuring a downstream anti-aliasing filter, allows transmission of the measuring data using shielded cables over distances of up to 25 m. This method allows the operation of the MNR recorder away from the probes outside the track‘s danger zone (Figure 2).

The evaluation unit is connected to the MNR through appropriate connectors (BNC) for portable measuring applications. Even a connection in compliance with IP 65 is possible. The system comprises an industrial PC with Intel CPU, 4GB RAM and a hard drive of appropriate size to record all measurements. Furthermore, an evaluation board for wheel sensors was incorporated into the computer. The integrated counting head (wheel sensor and evaluation board) allows automatic start of measuring data recording, so as to optimise measuring and recording time and data.

So as to file large data volumes any external storage media can be connected via USB. The evaluation logic has been programmed with LabView. Thanks to the use of a fast computer a single measuring run can be buffered for up to 1 minute, which in view of the on/off trigger is more than sufficient. Depending on the evaluation algorithm (linear or FFT), evaluation of data may take double to 6x the time. The measuring values determined by the test vehicle can be directly compared with the threshold values from TS50238-3 stored in the measuring system. Prior to a subsequent test run the results of the previous test run are, therefore, already known. Thus, the next test sequence may be adjusted or the effectiveness of modifications may quickly be tested (Figure 4).

Integration of the three antennas into a single housing and simultaneously maintaining maximum linearity (deviation <1.5 dB) over the entire specified frequency range from 10kHz to 100kHz and 100 kHz to 1.3 MHz, as well as compliance with size and position settings of the antennas according to TS50238 -3, were the biggest challenges. The mechanical mounting of the antennas on the rail also required development work, because, while any interference of the mount with the measuring results had to be avoided, the mounting procedure had to be fast, precise and reproducible. In addition, the antenna system is subject to mechanical stress from shock and vibration when vehicles cross over it.

Software and its settings have been designed so that customers can update the system themselves with little effort. This makes it possible to adjust the evaluation algorithms to the not yet fully defined curves of the frequency management.

7 Practical measurements and initial experience

After successful simulations with the Magnetic Noise Receiver in the laboratory of the manufacturer, a first test series with vehicles on a high-speed line of the ÖBB was prepared. To this end a track section of the Vienna West – Salzburg line, which is standardised for certification measurements, was selected. First, measurements were carried out on a certified traction unit, type 1116 Taurus. As there are conventionally determined measuring values available for that vehicle, it was possible to compare those with the data acquired by the MNR.

Meanwhile the test track was travelled by trains at speeds up to 200km/h, allowing documentation of the high-speed compatibility of the system and of the data consistency of the measuring values even under extreme operating conditions. Due to the computer system integrated in the measuring system the measuring results can be displayed immediately as a curve based on the diagrams from TS50238-3. For evaluation one can either use Fast Fourier Transformation (FFT) (Figure 5) which estimates the overall distribution, or discrete filter curves as described in TS50238-3. This provides short calculation times even for complete train sets. In parallel, the raw data are stored in order to allow for later evaluation using different criteria. In addition, antennas were subjected to

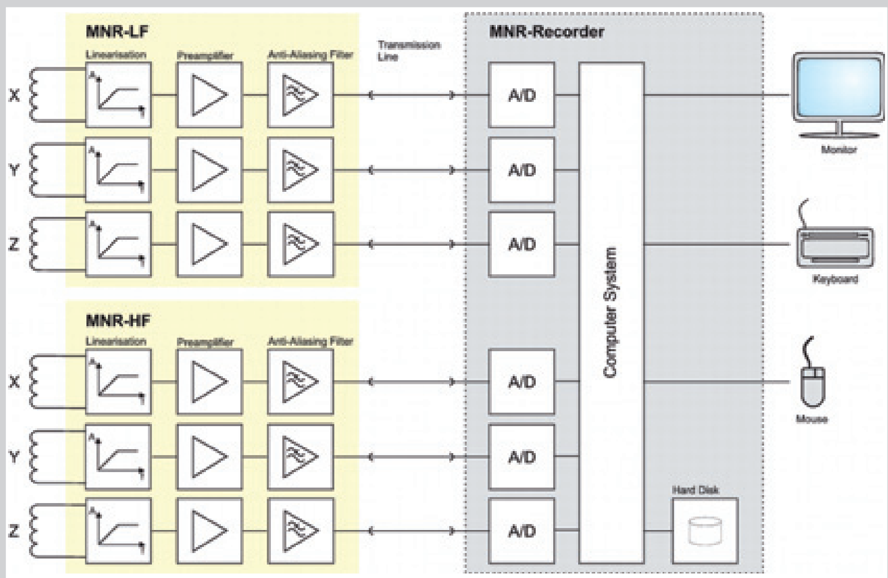

Figure 4: Block diagram of Magnetic Noise Receiver

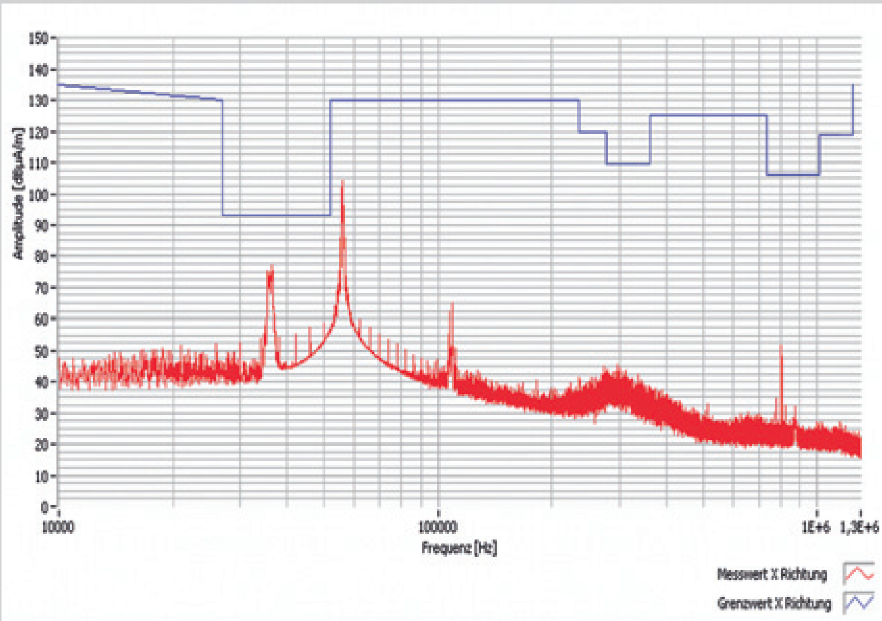

Figure 5: MNR online evaluation using FFT analysis

mechanical tests on the track. The geometry of the antennas as proposed in TS50238-3 does not provide sufficient mechanical protection of the antenna body. So as to determine the actual distance between the MNR measuring antenna and the wheel flange, modelling clay was applied to the housing: Based on the traces it was determined that the distance between antenna and wheel flange is a mere 3–5 mm for a slow passing vehicle. Due to the lateral oscillation of the wheel set caused by the side motion, this distance could even be smaller and damage the MNR measurement antenna mechanically. As the measuring system is attached with height-adjustable clamping brackets, antennas were lowered by 10 mm. Comparative measurements showed that lowering did not cause any evaluable changes in measuring results. The resulting effects on the standardised measuring array are yet to be discussed.

Another effect came about in the form of unexpected peaks in the 36 kHz and 56 kHz ranges, being the first constant, while levels within the second range increased and decreased with the vehicle movement. The explanation was only found when the test vehicle changed its running direction. Due to the change of running direction the LZB (linear train control) equipment on board had switched off automatically. This explained the cause of the peaks as measurements on a track with active LZB do not provide useful results regarding vehicle behaviour within these two frequency ranges.

8 Results and outlook

Summarising the first measuring series certainly yielded positive findings and therefore is to be deemed very successful. The MNR functionalities described, such as three-dimensional acquisition of the measuring fields in a single test run as well as real-time evaluation of measuring data in compliance with TS50238-3 and immediate evaluation of measuring results using FFT analysis, were confirmed in practice by these measurement series. The effectiveness of modifications carried out between tests runs can be immediately confirmed. The lessons learned are incorporated into further development steps such as improving cable connection and adjustment of the system for continuous deployment at the rail.

9 Where are interoperability efforts headed?

The purpose of interoperable certification is to ensure deployment capability of each vehicle all over Europe without need of additional country-specific measurements, where vehicles are measured only once using the standardised measuring procedures as set forth by TSI CCS (Technical Standards of Interoperability – Control-Command-Signalling) to confirm absence of interaction.

Compliance with interoperability conditions may also be of national importance in certain situations: Internationally relevant corridors will be equipped according to interoperability criteria to allow transit of compliant vehicles, which, however, may not leave such corridors.

Thus, regional lines would not need to be "interoperable" provided through traffic is not important. Here, certification of vehicles according to national or (quite common these days) regional "Specific Cases" (= "special fault conditions" for EMC) would suffice.

For the infrastructure facilities in different countries, interoperable equipment means that – among other things – all track circuits and axle counting systems deployed will have to comply at least with the features as described in TS50238-2 and TS50238-3 or, for instance, deploy axle counters from the list of "Preferred Axle Counters". New developments for track circuits and axle counting systems will have to demonstrate that their immunity to interference fields is sufficiently above the admissible rolling stock levels stated in the TSI CCS diagrams.

It is significant that even the infrastructure segment will see the deployment of equipment physically and electrically subject to the same interference criteria as axle counters. The compatibility of traction units with track switching equipment can be adequately documented for the detectable frequency ranges using measuring methods such as those described for MNR. It seems, therefore, desirable to evaluate the immunity of any infrastructure based on the same curves. Some work will yet have to done to provide secure, reliable and consistent evaluation guidelines.

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LITERATURE

[1] TS50238-2 Bahnanwendungen – Kompatibilität zwischen Fahrzeugen und Gleisfreimeldesystemen – Teil 2 – Kompatibilität mit Gleisstromkreisen (Railway applications – Compatibility between Rolling Stock and Train Detection Systems – Part 2 – Compatibility with Track Circuits)

[2] TS50238-3 Bahnanwendungen – Kompatibilität zwischen Fahrzeugen und Gleisfreimeldesystemen – Teil 3 – Kompatibilität mit Achszählern (Railway applications - Compatibility between Rolling Stock and Train Detection Systems – Part 3 – Compatibility with Axle Counters)

ZUSAMMENFASSUNG

Magnetic Noise Receiver

Zielstellung der interoperablen Fahrzeugzulassung ist die Einsetzbarkeit von Triebfahrzeugen im gesamteuropäischen Raum ohne zusätzliche länderspezifische Messungen. Diese sollen nach standardisierten Messprozessen der TSI CCS (Technische Standards für Interoperabilität – Control-Command-Signalling) nur einmal vermessen werden und müssen Rückwirkungsfreiheit aufweisen. Zur Evaluierung von einheitlichen Störgrenzen ist die Bekanntheit der Störfestigkeit der Infrastrukturanlagen eine Grundvoraussetzung. Die Störgrößen des rollenden Materials müssen des Weiteren genau, vergleichbar und nachvollziehbar ermittelt werden.
Die Richtlinienreihe EN50238 sieht dazu unter anderem Mess- und Bewertungsverfahren vor, welche dies belegen sollen. Das Frequenzmanagement wird auf Basis der in der TS50238-3 1 definierten Verfahren im “Interface Document” der aktuell überarbeiteten TSI CCS festgelegt werden.
Von Frauscher Sensortechnik wurde diesen Bedingungen entsprechend das System “Magnetic Noise Receiver – MNR” entwickelt, welches Messkurven in Echtzeit an der Schiene entsprechend den geforderten Bedingungen aufzunehmen, aufzuzeichnen und auszuwerten in der Lage ist.
In Kooperation zwischen ÖBB-Infrastruktur AG und Frauscher Sensortechnik GmbH konnten Messreihen bestätigen, dass das mobile Messsystem auf Basis INTEL-Industrie-PC die Anforderungen der TS50238-3 hinsichtlich Messmethodik und Auswertung vollständig zu erfüllen in der Lage ist. Funktionalitäten des MNR wie dreidimensionale Erfassung der Messfelder (X-Y-Z Achse), Geschwindigkeit, Messtriggerung und Echtzeitauswertung bei einer einzigen Messfahrt konnten beim Praxistest in Feldmessungen bis 200 km/h überzeugen.