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ISSUES OF SIGNALING SYSTEMS APPLICATION IN THE TRAMWAY INFRASTRUCTURE – A CASE STUDY

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Abstract
The application of state of the art track circuits is getting more and more popular on the Polish tramway infrastructure. The electromagnetic interference between traction return current and track circuits has become significant not only in the railways. The paper describes implementation of modern track circuits in the Polish tramway infrastructure and related electromagnetic issues. The on-site survey and proper measurements were performed to identify the electromagnetic interference problems. Authors conducted the analysis concerning the track circuit application in the tramway infrastructure, presenting its weaknesses that influence safety and reliability of the system.

Introduction
Electric traction vehicles are equipped with power electronics equipment for traction and non-traction purposes. Power electronics systems enable smooth determination of traction characteristics depending on a set duty-cycle of motion. Structure of modern converters consists of semiconductors, typically IGBT, which apart from many advantages, posses a range of drawbacks - there are sources of electromagnetic noise. The latter makes the requirement of the electromagnetic compatibility (EMC) provision.

In typical electric traction systems, running rails (RR) are operating as return conductors as well. As a result, the vehicle's input current flows not only in an overhead catenary (or 3rd rail) but also in the running rails. It could be expected though, that current harmonics flow in the RR, could be the reason of EMC issues.

Signaling systems on railways
For an appropriate, safe and reliable organization of the rail transport the train detection systems have to be applied [1,2,3,4,5,6.16,17,18,19]. In the DC railway, track circuits (TC) used for train detection operate with AC signals with various frequencies and amplitudes (depending on the system). In the most common types of TCs, the signaling current flows via the RR between a transmitter and receiver. The malfunction of the TCs due to the presence of higher current harmonics in the vehicle's return current is intolerable and may have catastrophic consequences.

That is the reason why every prototype of rolling stock has to be assessed during homologation and commissioning procedures and be tested against a set of standards [11, 12, 13, 14]. It makes that the EMC issues between 'signaling and traction power' systems are reduced to minimum and railway operation, from the point of view of conducted interference, becomes reliable and safe.

Tramway systems in Poland
Typically no signaling system is used in 14 Polish tramway systems. However, nowadays, track circuits application is becoming more and more popular on the tramway tracks - especially in depots and loops.

This fact causes a stir, considering safe and reliable operation of the whole urban rail system. Tramway infrastructure operators, in most cases, have no experience in the field of signaling and vehicle detection systems, which were mostly used only at simple one track sections when passing loops were applied (or not). Nevertheless, urban rolling stock, from the point of view of the EMC phenomena, is exactly the same as the one applied on railways (it is also a source of higher harmonics). As a result, the new interface appears in an electric traction urban system - between traction return current and signaling current in a track (Fig. 1).

Due to the above mentioned reasons, it should be required to test the tramway rolling stock against conducted interference; this however is not a common practice in Poland. Of course, a tramway transportation system is roughly different than the railway one. In most cases, the track circuit failures will not have such critical impact on the people safety like in the case of railways (lower speeds, greater deceleration etc.), but they still influence the system organization. Consequently, the right side failures are becoming a new and significant area of EMC concern.

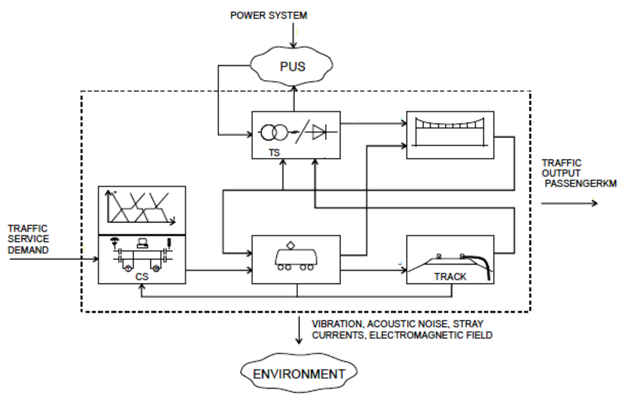

Fig. 1 Electric traction rail urban system and its internal and external influences [16].

Application of track circuits in a light railway transportation system (i.e. a tramway system) has to be performed simultaneously with appropriate testing. First of all, the criteria for conducted emissions have to be specified, secondly, the track circuit manufacturers should declare the immunity of their equipment to such disturbances. If these conditions are not applied, the implementation of the advanced track circuits has to be out of concern.

Track circuit application – a case study

During modernization of a tramway section in one of the Polish cities, track circuits were implemented so to improve capacity and provide better organization. In most cases, providing state-of-the art solutions on the infrastructure during modernization is inseparable from application of a modernized and modern rolling stock.

In this case, the modernized rolling stock was equipped with voltage source inverters or choppers. It could have been predicted that considerable spectrum of current harmonics would be present in the return current of such vehicles.

But unfortunately, the EMC issue, concerning the negative interaction between rolling stock and track circuits appeared. However, track circuits failures became a serious obstacle for an infrastructure operator. Huge disorganization of tramway operation caused intolerable consequences.

It was noticed that track circuits failures were strictly related to one type of a rolling stock (4 x AC 100 kW motors, voltage source inverters).

The infrastructure operator contracted Electric Traction Division, Warsaw University of Technology (ETD) to conduct appropriate measurement of the rolling stock and perform local surveys [7,8, 9].

Measurements

After on-site investigation (on-site survey), it was defined that a large number of track circuits applied in the area of concern were operating with various frequency spectrum (Fig. 2). Moreover, some additional bonding in the traction return system had been implemented, which could have also been an issue, and caused inappropriate behaviour of track circuits.

ETD performed a lot of tests, taking into consideration plenty of scenarios (different operation of vehicle: acceleration, deceleration, electric braking, costing, mechanical braking, and riding with different ranges of speed). The EMC tests contained either measurement of conducted or radiated emission. Radiated emission was performed against the EN 50121-3-1[14] standard. The measurements were done for the relevant part of CISPR A frequency range [11] with application of Agilent spectrum analyser, Schwarzbeck loop antenna and A.H Systems broadband current probe.

(Note: term 'radiated emission' is typically used for the electromagnetic field emission above 30 MHz. However, to distinguish measurement performed with current probe application at the input circuit of the inverter (conducted emission) with those measurements conducted with application of the loop antenna, authors decided to provide the term 'radiated emission' for the magnetic field measurements within the CISPR A [11] frequency range - 9 kHz - 150 k HZ).

The stationary and slow moving tests were conducted. Prior to the emission tests, the acquisition of the ambient noise was done, which is typical for such EMC measurements. To achieve the most reliable and repetitive results, the tests were performed on separate section at night. The results of the measurement can be seen in Figures 1-5.

At the beginning the conducted emission tests were done. The broadband current probe was set in the input of the traction inverter (+660 V DC - catenary voltage). The probe was connected with a spectrum analyser through 50 Ohm, a good quality cable. The cable losses and transfer impedance of the probe have been considered to achieve an appropriate values and units of AC interference currents.

At the beginning the ambient noise was measured, which means that inverter was under voltage but not operated. During the first part of the tests, settings of the spectrum analyser (resolution bandwidth (RBW) = 200 Hz, sweeping time = 20 ms) were according to suggested by [11] (Fig. 2). While in the second part, the RBW was set to minimum to obtain more selective results (RBW = 10 Hz, sweeping time 200 ms) (Fig. 3). Additionally 'max hold' mode was enabled to receive the highest possible interference. The measurements in the 9 - 150 kHz frequency range were conducted to get an overview of the tram's current spectrum, whereas those performed within the range 20 - 30 kHz were dedicated to the particular track circuits failure modes investigation.

As it can be noticed from the presented graphs (Fig.2, Fig.3) the high frequency currents appear practically in the entire CISPR A band. The current peaks appear not only in the frequency range of applied (and disturbed) track circuits, but also within the range of higher frequencies. The most interesting, from the point of view of EMI, frequency range is presented in Figure 3. The specific harmonics of currents are present in the input current as it was predicted. The frequency range of the TC 1 is in the middle of input current peaks. However, the frequencies of operation of all other disturbed TCs are overlapped with the higher harmonics taken by the vehicle. This situation may be dangerous for the reliable operation of the track circuits.

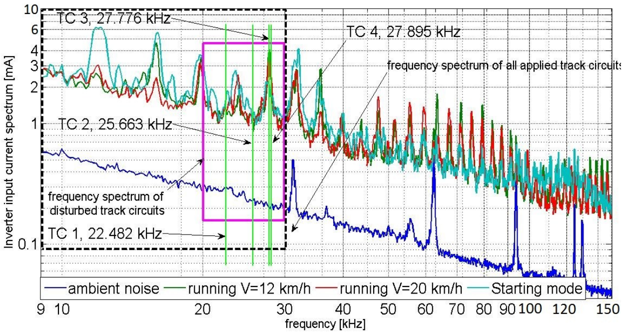

Fig.2 Results of the conducted emission test during different scenarios. The frequency of applied and disturbed track circuits are matched.

For the next step of the project, ETD performed measurements of radiated interference [14]. Similarly to the previous measurements, the test started with the acquisition of the ambient noise. The difference of the ambient noises during stationary (Fig. 5, 6) and slow moving (Fig. 4) test is related with different RBW application of the spectrum analyser (which was set to the value of 200 Hz during stationary test, and 1 kHz during slow moving test). The further explanations and analysis of RBW application during EMC tests of moving vehicles can be found in [7, 8].

It can be noticed (Fig. 4) that magnetic field within the interested frequency range is higher than the ambient noise; however it is slightly below the limit specified for this kind of test. The same can be observed for the stationary test (Fig.5).

The interesting fact is that just before motoring stage (but still while stationary), the peak of magnetic field, which overlapped the TC 3 and TC 4 frequencies, appeared (Fig. 6).

There is a probability that harmonic current of specified frequency flowing in the tramway circuit would be coupled (due to magnetic coupling mechanism) into the RRs, causing failures of track circuits. However, from the point of view of the standard, the emission is below the limit, even if a more restrictive one is applied (for stationary test, although those peaks have been results of the beginning of motoring operation).

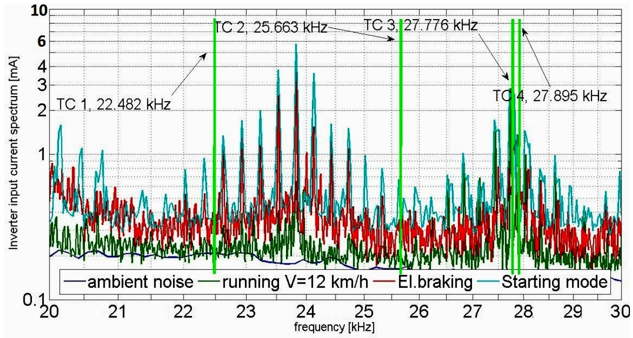

Fig.3 Results of the conducted emission test during different scenarios within the range of disturbed track circuits operation. The frequencies of disturbed track circuits are matched.

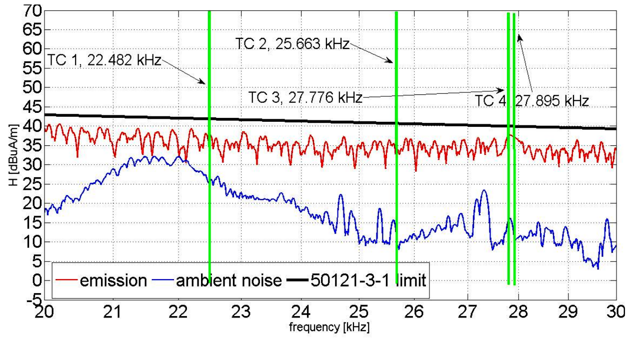

Fig.4 Results of the radiated emission during slow moving tests [14] within the range of disturbed track circuits operation. The frequencies of disturbed track circuits are matched.

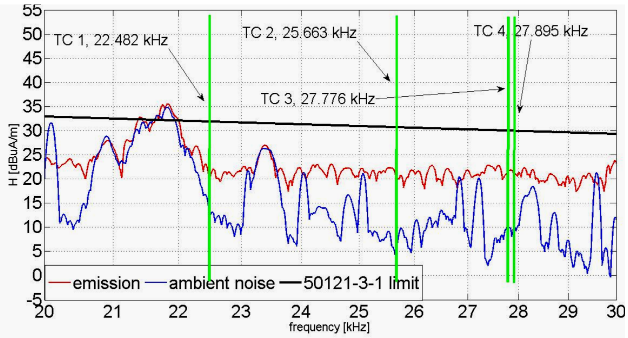

Fig.5 Results of the radiated emission during stationary [14], within the range of disturbed track circuits operation. The frequencies of disturbed track circuits are matched.

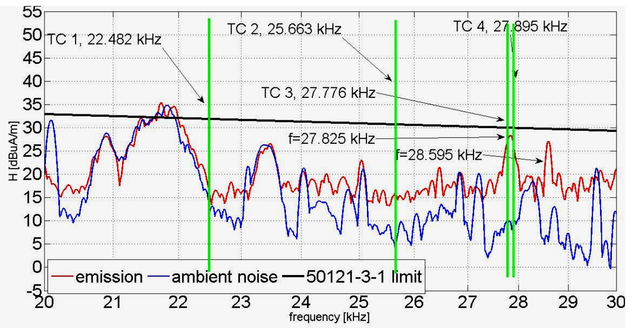

Fig.6 Results of the radiated emission during stationary test just before starting [14], within the range of disturbed track circuits operation. The frequencies of disturbed track circuits are matched.

Conclusions

Appropriate interpretation of the measurement results requires further attention. According to the enclosed diagrams (Fig. 2÷6), it could be stated that the tram might be the source of interference causing the track circuits failures. The current flowing in the tram's electrical circuits contained the higher frequencies components overlapped with the frequencies utilized by the applied signaling systems. Furthermore, these could be also seen in the magnetic field emission in the vehicle's surroundings.

However, the above mentioned results are not sufficient reasons to state that the tram is the source of EMI in the infrastructure.

Fortunately, prolonged works and cooperation of the tram inverter and track circuits manufactures with infrastructure operator and ETD were successful and the disturbances were eliminated. The slight changes were applied in the tramway electronic circuit (filters and electrical bonding improvement) and in the area of disturbed infrastructure (earthing and bonding analysis).

The main aim of this paper was not to present how to solve the problem of track circuit failures in the tramway infrastructure, but to emphasize the issue of insufficient preparation of signaling system implementation at such infrastructure. Issues related to EMI are complex and have to be analysed not only by infrastructure operators and manufactures of traction power electronics systems or track circuits, but also by appropriate institutions that will be responsible for developing specifications, standards and guidelines. Only after complete and comprehensive preparation of the overall system, the interfaces of all of the traction subsystems will be electromagnetically compatible and safe.

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