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Evaluation of the Electromagnetic Effect of Traction Rolling Stock on Track Circuits

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ABSTRACT

The regulations regarding railways currently in force in Bulgaria require that each new type of locomotive, to get access to railway infrastructure, must undergo a procedure for checking its electromagnetic effect on functioning of track circuits.

The relevant testing was carried out for seven types of AC and DC track circuits and for six types of locomotives intended to be put into operation (five electric locomotives and a diesel locomotive).

Schematic diagrams of testing conditions are presented. During the tests the voltage waveform, frequency, and level rates at the terminals of the track receiver (on the track relay coil) were recorded for a free (normal (common) mode) and occupied (shunt mode) track circuit during the action of return traction current of electric locomotives, as well as during the action of impacts caused by operation of electrical equipment located in the body and under the frame of the diesel locomotive.

For electric locomotives, the tests were carried out during the shunting of track circuits (of a tested one and of the track circuit adjacent to it), starting from the rest, lowering and raising pantographs. For a diesel locomotive, tests were carried out in a stationary mode, when inner wheelsets shunted the insulating joints of two adjacent track circuits and for different cases of arrangement of the equipment of the relay and receiver ends. During the tests, the state of the armature and contacts of track relays was monitored. The amplitude of the recorded interference was compared with voltage of reliable switching off/on of track relays/track receivers. It was found that during the shunt mode, the recorded residual voltage in the track receiver under the action of the electric locomotive was 50 or more times lower than the reliable operate voltage and 33 or more times lower than the reliable drop-out voltage of the receiver. For a diesel locomotive, the results turned out to be similar, except for the case of shorter DC track circuits, where the amplitude of the interference was higher, but without a dangerous effect on the shunt mode.

Based on the results of the tests, it was established that all types of track circuits used on the railways of Bulgaria are resistant to electromagnetic interference emanating from tested samples of traction rolling stock.

Keywords: railway, traction rolling stock, track circuits, electromagnetic impact.

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1. **Background.**

In accordance with the regulations regarding Bulgarian railways currently in force, each new type of locomotive, which is the property of a local or foreign carrier, to get access to the railway infrastructure, must undergo an assessment procedure for compliance with the requirements of national technical and safety regulations[1]. One of these testing procedures is related to assessment of the electromagnetic effect of traction rolling stock on operation of track circuits to determine their electromagnetic compatibility. The need for such a testing is due to two reasons:

• on the one hand, more and more powerful locomotives are currently being put into operation and they use modern electronic devices (rectifiers, converters, etc.), which produce electromagnetic radiation and generate interference that did not exist at time of development and implementation of the corresponding types of track circuits since such rolling stock did not exist either.

• on the other hand, track circuits used in Bulgaria are not used in most of the European Union countries.

Assessment of electromagnetic compatibility of track circuits with modern rolling stock can be solved in two ways:

• full-scale testing of the electromagnetic effect to reveal probability of dangerous consequences of relevant impacts, for example, of turning on of the track receiver of the track circuit during the shunt mode.

• checking the emissions (radiation) of the newly produced rolling stock in the bandwidth already occupied for operation of track circuits.

The *subject* of the research described in the article refers to methodological issues and test results regarding the first method for assessing electromagnetic compatibility of rolling stock with track circuits, used within the railway infrastructure of Bulgaria, namely with:

• DC track circuits with 50 Hz AC electric traction, manufactured in the former GDR.

• Track circuits developed and produced in ex-Soviet Union, comprising:

– 75 Hz pulse track circuits;

– 75 Hz code track circuits;

– 25 Hz pulse track circuits;

– 25 Hz phase-sensitive track circuits;

– 71–83 Hz track circuits with heterodyne control of short circuit of insulating joints.

• Shorter electronic track circuits, type KERV, 30 kHz, of Bulgarian design and production.

Due to ongoing modernization of railway infrastructure, some types of track circuits are no longer in use, but at the time of testing, that will be discussed below, they were still in operation. Nevertheless, the author has considered it appropriate to cite the results obtained for them, since they are used in other countries, particularly Russian railways, and may be of interest to the readers of the journal.

2. **Method of testing**

It is known that track circuits (TC) operate in four modes: normal, shunt, control, and automatic locomotive signalling modes. Due to various circumstances, the latter mode did not find application on the railways of Bulgaria, therefore, the test of the effect of traction rolling stock on track circuits was carried out for normal and shunt modes. The control mode, due to the complexity of implementation, was not considered.

The practice shows that the electromagnetic interference that can affect operating modes of track circuits is mainly generated by the return traction current flowing in rails together with its harmonic components, as well as emissions from electrical equipment and units mounted in the body and under the frame of traction and non-traction rolling stock (passenger wagons).

Testing the electromagnetic effect (electromagnetic compatibility) on track circuits was carried out during full-scale tests with registration of the voltage waveform, frequency and level rates at the terminals of the track receiver (at the track relay coil) with a free (normal (common) mode) and occupied (shunt mode) track circuit during periods of exposure to return traction current of electric rolling stock, as well as during periods of impacts caused by operation of electrical equipment located in the body and under the frame of traction rolling stock with autonomous traction.

All tests were carried out for reference track circuits corresponding to the types of track circuits used at railway blocks and stations using a circuit diagram, its example here (Pic. 1) refers to a phase-sensitive track circuit.

For other types of track circuits, the difference in the circuit diagram is associated

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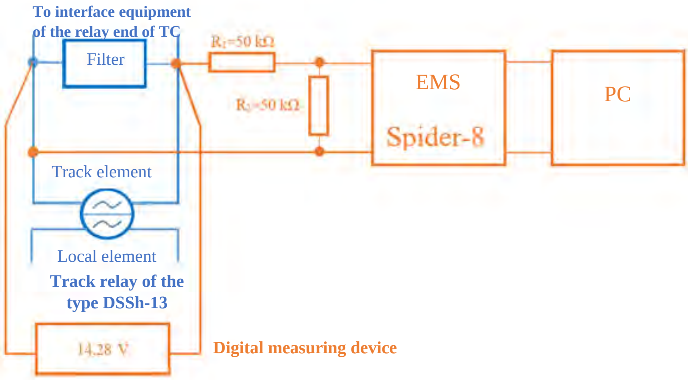
[1] National reference document of the Republic of Bulgaria. «Railway Administration» Executive Agency [*Национален референтен документ на Република България. Изпълнителна агенция «Железопътна администрация»*], Sofia, 2016.



Pic. 1. R_1, R_2 – voltage divider resistors; EMS – electronic measurement system Spider-8; PC – personal computer [2].

with the type of track relay, and in the case of DC track circuits, with the absence of a filter.

During the tests, all electrical equipment located in the body and under the locomotive frame (transformers, converters, rectifiers, traction and non-traction motors, lighting, climate installations (if any), automatic locomotive signalling devices (relevant for imported locomotives), and radio communication devices) were switched on, and when it was possible, operated at extreme modes. Testing was conducted during short-term entry of locomotives in the country to obtain permit for supposed delivery. Each testing type comprised two experiments due to time constraints within established maintenance time intervals in train traffic.

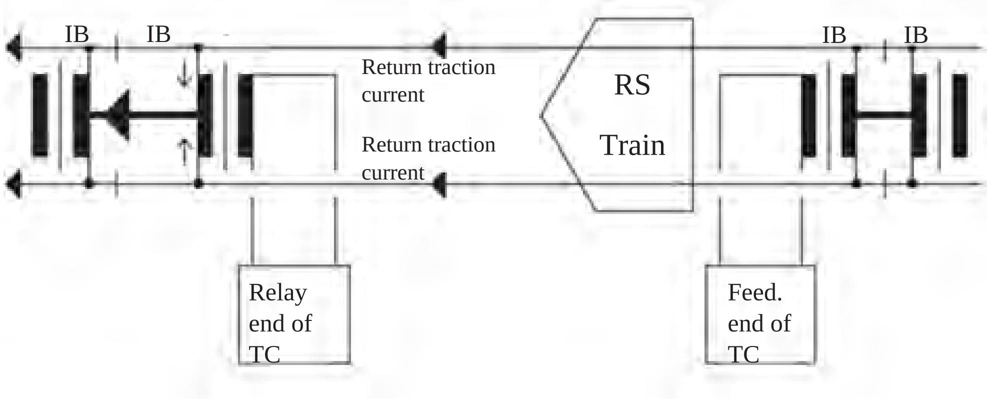
a. Additional conditions for testing electric locomotives with electric traction of 50 Hz, 25 kV AC.

The tests of electric locomotives were carried out in compliance with the following additional conditions:

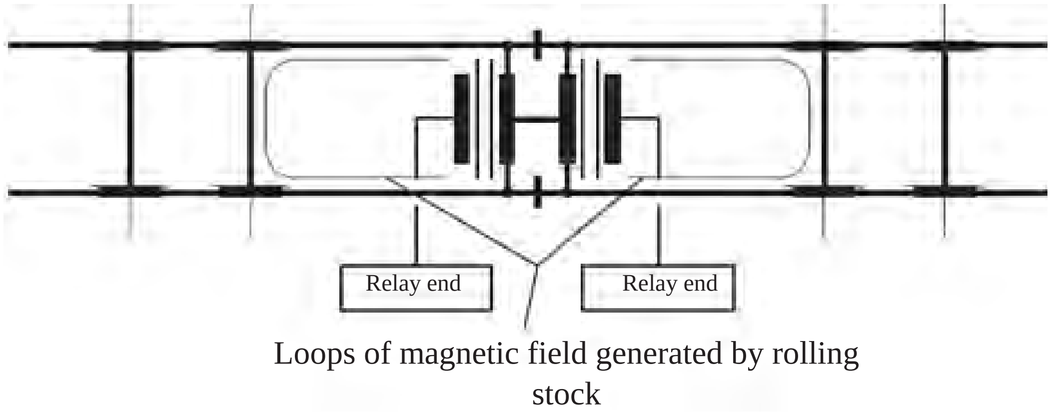
• when a train/a locomotive approaches an unoccupied track circuit (normal mode), as well as when it is occupied (shunt mode), it is necessary that the return traction current flows through the receiving or (as particular case) through relay end of the TC (Pic. 2), when this end is at the exit from the TC [1].

• on the corresponding section where the locomotive was operated, there would be no other traction rolling stock, besides the tested one.

During the tests of the electric locomotive, the voltage waveform, frequency, and level rates at the terminals of the track receiver (on the track relay coil) were recorded when the locomotive was moving to an unoccupied TC, during its occupation, and also when starting from rest with the maximum possible tractive effort. The return traction current (in compliance with safety conditions) was measured with a Dietze's clamp meter at the points where



Pic. 2. Conditions of electric locomotives testing [1].



Pic. 3. Conditions of diesel locomotive testing [1].

the impedance bonds (IB) were connected to the rails.

b. Additional conditions for testing diesel locomotives.

In case of diesel traction with electric gear, an additional rule was observed which was the most difficult one from an operational point of view: in the shunt mode of the tested track circuit, the diesel locomotive should stay in a stationary state on the track so that the points of connection to the rails of the equipment of the receiving (relay) end of the track circuit were located between the points of contact of the inner wheelsets with the rails [1].

The tests were carried out for different cases of arrangement of the equipment of two adjacent track circuits (two receiving ends, as well as a feed and relay end for options with and without impedance bonds).

During the tests of the diesel locomotive, the voltage waveform, frequency, and level rates at the terminals of the track receiver (on the coil of the track relay) were also recorded in stationary conditions, while driving and starting off with the maximum possible tractive effort. When the tests were carried out on an electrified site, it was necessary to make sure that at this moment the return traction current in rails, measured by the Dietze current clamp, was equal or close to zero.

3. Scope of tests

At different times, six 50 Hz, 25 kV AC electric locomotives and a diesel locomotive were subject to testing the electromagnetic effect of traction rolling stock on track circuits.

The following locomotives were tested:

1) Electric locomotive with a capacity of 6400 kW (maximum return traction current of about 255 A). During the tests, a freight train weighing 1100 tons was coupled to it.

2) Electric locomotive with a capacity of 6000 kW (maximum return traction current of about 240 A). During the tests, an auxiliary electric locomotive was coupled to it, which, to provide the load, worked in the mode of rheostatic braking.

3) Electric locomotive with a capacity of 5600 kW (maximum return traction current of about 225 A). During the tests, a freight train weighing 1000 tons was coupled to it.

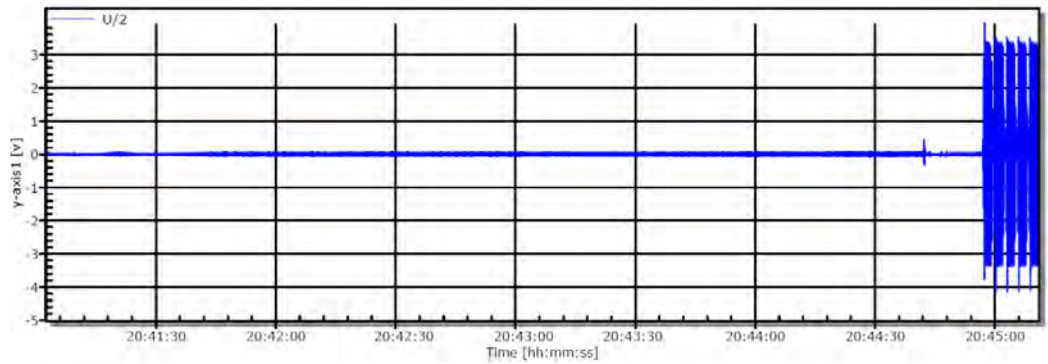
4) Electric locomotive with a capacity of 5600 kW (maximum return traction current of about 225 A). During the tests, an auxiliary electric locomotive was coupled to it, which, to provide the load, worked in the mode of rheostatic braking.

5) Electric locomotive with a capacity of 5500 kW (maximum return traction current of about 220 A). During the tests, an auxiliary electric locomotive was coupled to it, which, to provide the load, worked in the mode of rheostatic braking.

6) Electric locomotive with a capacity of 4250 kW (maximum return traction current of about 175 A). During the tests, an auxiliary electric locomotive was coupled to it, which, to provide the load, worked in the mode of rheostatic braking.

7) Diesel locomotive with a capacity of 1600 kW.

In all cases, an electric locomotive was located at the end of the train, which already had the right to access the railway infrastructure. It carried out



Pic. 4. Pulse track circuit of 25 Hz (shunt mode and starting from rest) [2].

movement of a train/a test locomotive to test objects, as well as auxiliary movements during the tests. During some tests in rheostat braking mode, it was the load/commodity for the test locomotive. At time of testing, this locomotive was not connected to the overhead line.

4. **Results of tests**

Tests of electric locomotives and of a diesel locomotive have revealed a series of effects.

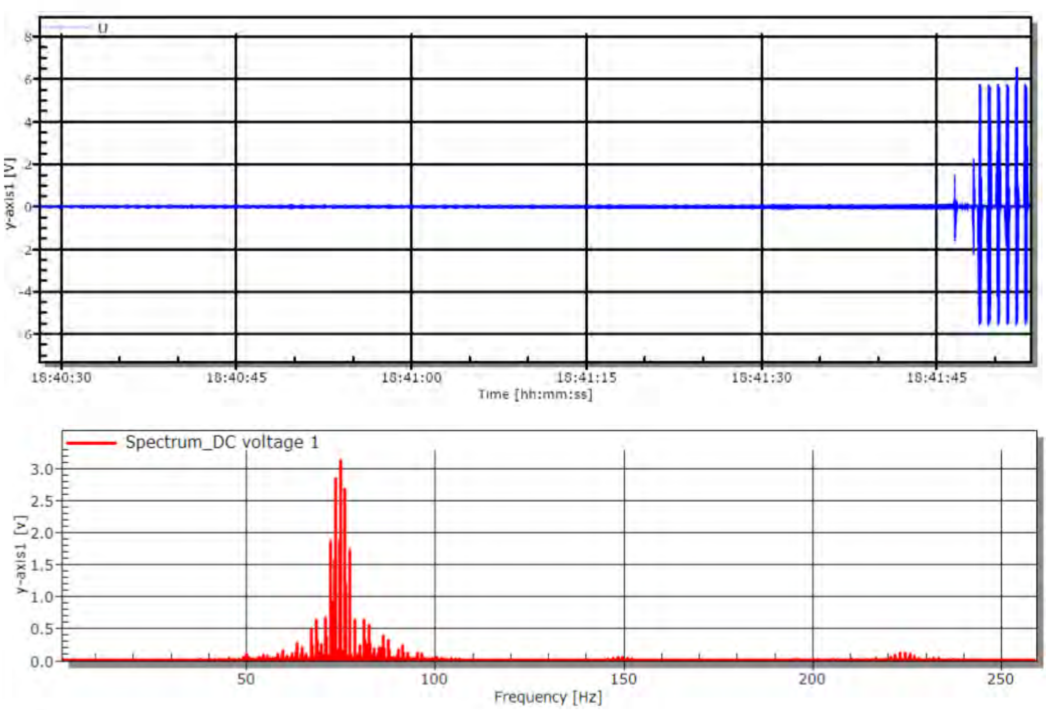
4.1. Effect No 1: Shunting track circuits and locomotive starting from rest

4.1.1. Tests of electric locomotives

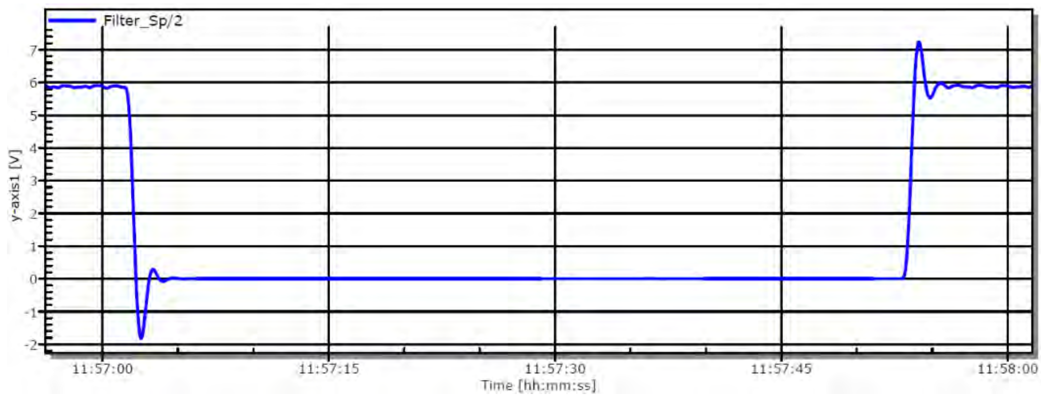
Pics. 4–7 show fragments of the oscillograms demonstrating the effect of shunting the reference types of track circuits during tests under the influence of the indicated locomotives. Due to similarity of the obtained results, the number of oscillograms is deliberately limited.

The above oscillograms show that during the tests in the normal mode as well as in the shunt mode, no interference was detected that might have led to abnormal operation of all reference types of track circuits. Wherein:

1) In case of a traction vehicle moving towards an unoccupied track circuit, no changes were observed in the waveform and amplitude of the signal current. The frequency spectrum of the alternating current track circuits contained only the signal current frequency (Pic. 5). In case of a direct current



Pic. 5. Code track circuit of 75 Hz (shunt mode and starting from rest). Frequency spectrum at the terminals of the pulse track relay [2].



Pic. 6. 71–83 Hz track circuit with control of short circuit of insulating joints with heterodyne (transition from normal to shunt mode, shunt mode and transition to normal mode) [2].

track circuit, in addition to traction current frequency (50 Hz), a strong second harmonic was also observed during starting from rest (Pic. 7), which together did not affect functioning of the track circuit.

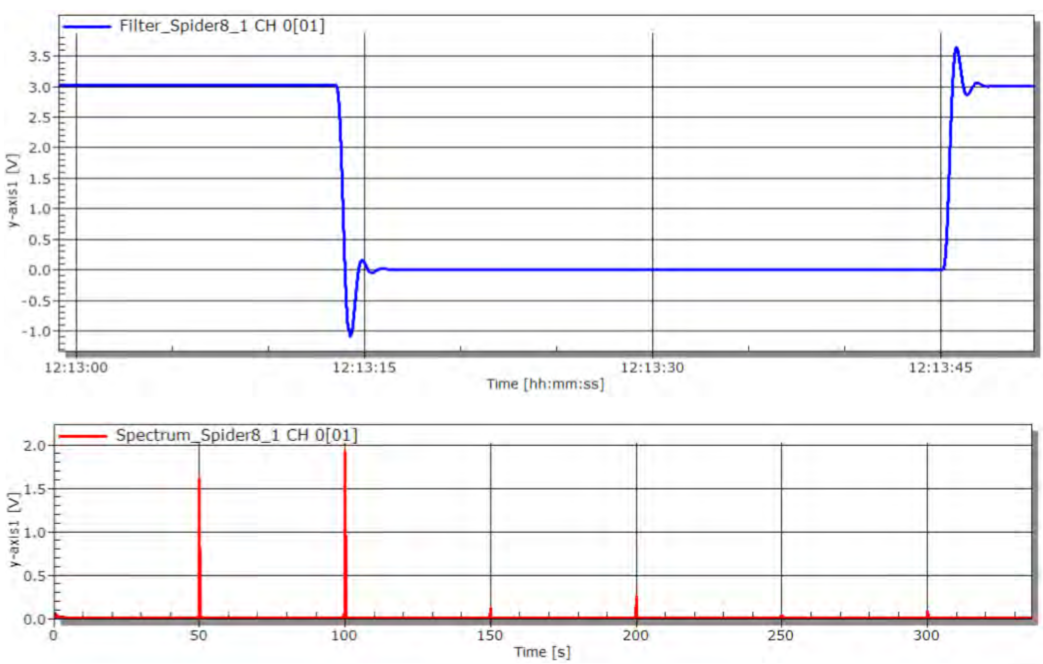
2) When the feed end of the track circuit was shunted and when movement was carried out to the receiving end, the track receiver (track relay) steadily passed from «energised» state to «de-energised (no current)» state, and when the track circuit was released, it passed from «de-energised» state to the «energised» state.

3) In the shunt mode, the residual voltages recorded at the track receiver were 50 or more times lower than the reliable operate voltage and 33 or more times lower than the reliable drop-out voltage of the receiver.

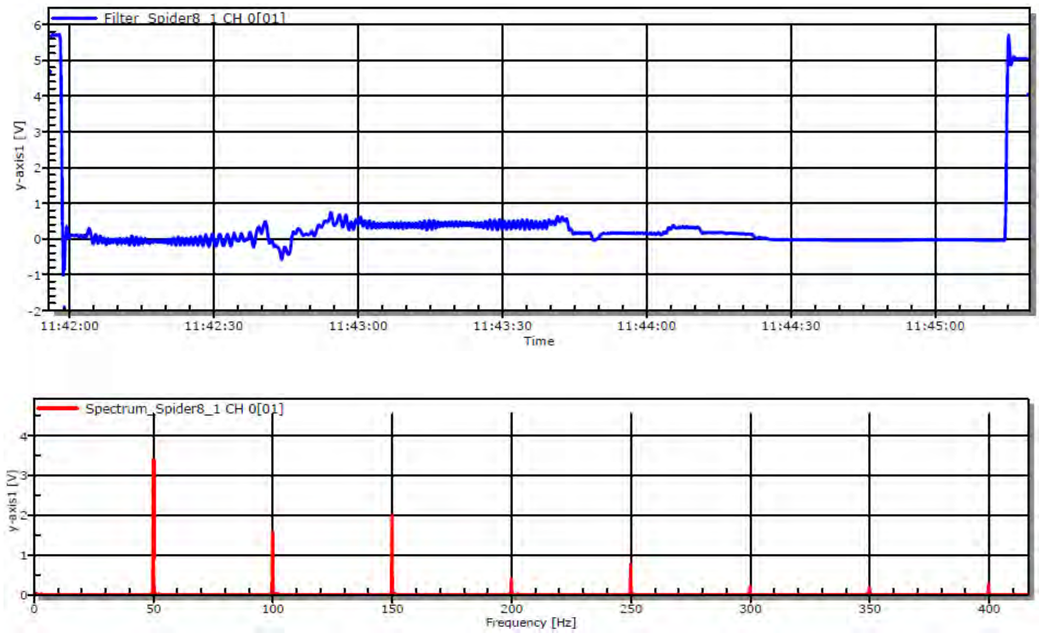
4) If locomotives occupied:

• A pulse track circuit, then the movable contact of the pulse track relay stably rested against the fixed contact without displacement or bouncing.

• A track circuit with a neutral track relay or with a neutral repeater of a pulse track relay, then the armature was stably in drop-out position. Before occupation of the track circuit, as well as after its release, the anchor was stably pulled. In both conditions, no attempts to move or bounce were observed.



Pic. 7. DC track circuit (transition from normal to shunt mode, shunt mode and transition to normal mode). Frequency spectrum of the signal at the terminals of track relay when starting from rest [2].



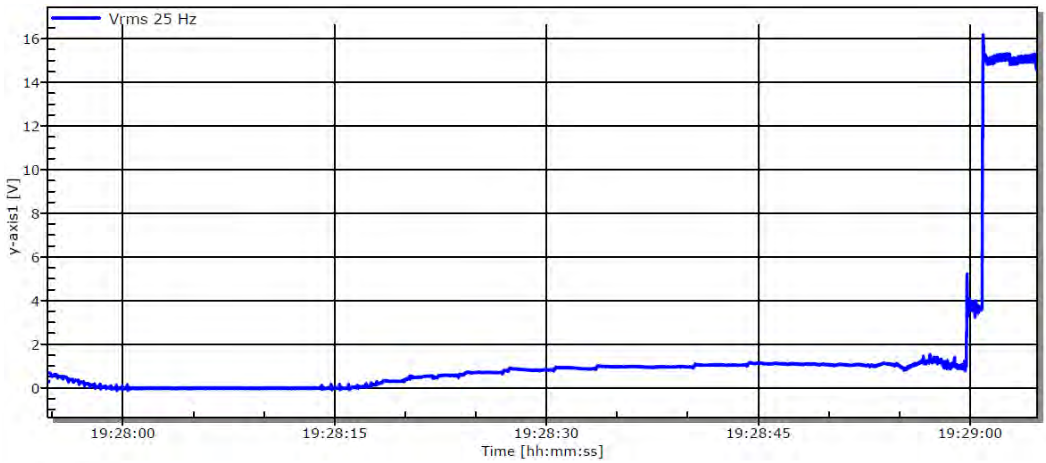
Pic. 8. DC track circuit (transition from normal to shunt mode, shunt mode, starting from rest and transition to normal mode). Frequency spectrum of the signal at the terminals of track relay [2].

• A phase-sensitive track circuit, then a sector of the track relay stably rested against the lower limiting roller without displacement and/or vibration. Before occupying the track circuit, as well as after its release, the relay sector stably and motionlessly rested against the upper limiting roller.

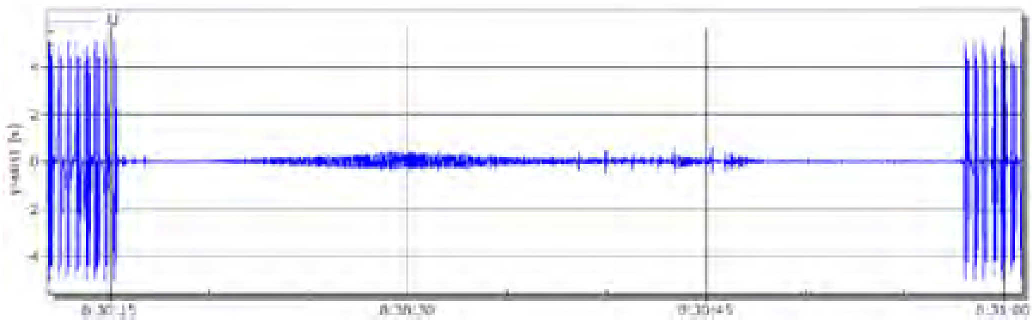
4.1.2. Tests of a diesel locomotive

During stationary tests of a diesel locomotive under the conditions shown in Pic. 3, no abnormal switching on of the switched off track receiver/track relay was observed.

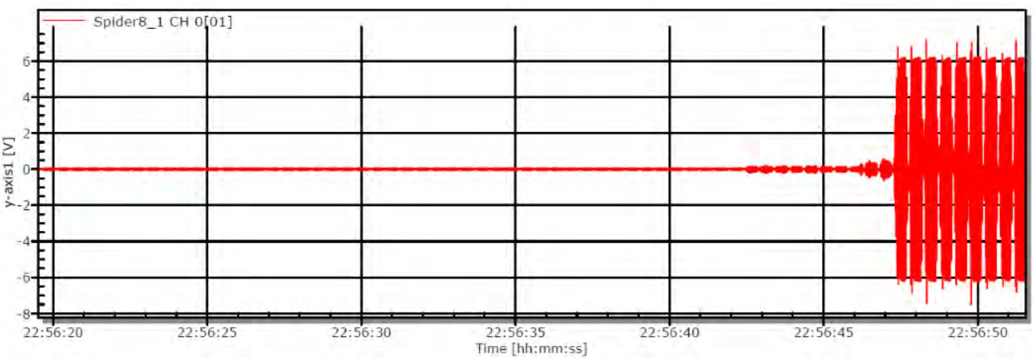
Under normal conditions, as well as in shunt mode, including starting from rest, no cases of abnormal functioning of reference types of track circuits were revealed. The results are the same as in the cases of testing electric locomotives (Pics. 4–7). However, in case of shorter DC track circuits, during locomotive's braking and starting from rest, noise with an amplitude of about 0,7 V was detected (Pic. 8). At the same time, a 50 Hz signal was present in the frequency spectrum with the highest amplitude, which is unusual for harmonic components of the rectified supply voltage of



Pic. 9. Phase-sensitive track circuit with the relay of DSSh-13 type (starting from rest and transition from shunt mode to normal mode) [2].



Pic. 10. 75 Hz pulse track circuit [2].



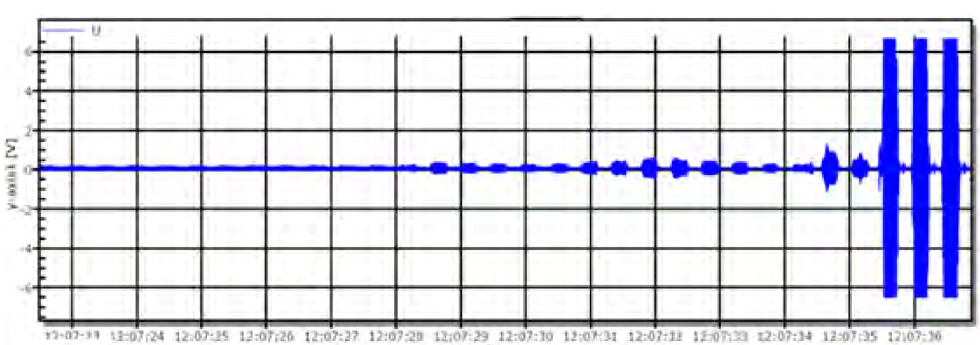
Pic. 11. 25 Hz pulse track circuit (influence of an electric locomotive) [2].

DC track circuits. Therefore, it should be considered that the tested locomotive was the source of 50 Hz interference and of 50 Hz-fold noises, which can be explained by electromagnetic emissions due to switching of its individual units. This is confirmed by the fact that the noise has a varying amplitude, which is associated with transients. If we accept that a diesel locomotive generates those noises, which could not be absolutely proven, then the experiment showed unequivocally that they do not have a dangerous effect on the shunt mode of a DC track circuit.

In case of phase-sensitive track circuits, when the diesel locomotive started from rest and during transition from shunt to normal mode, interference with an amplitude of about 1,5 V was observed, which did not affect the state of DSSh-13 relay sector which was in a stable lower position (Pic. 9).

4.2. Effect No. 2: Generation of interference when lowering and raising the pantograph of electric locomotives during passage of the so-called «neural inserts»

Pic. 10 shows an oscillogram of voltage of the track receiver (pulse track relay type IMVSh-110 after FP-75 filter) of the 75 Hz pulse track circuit in shunt mode during the test of the above-mentioned locomotive No. 1.



Pic. 12. 75 Hz pulse track circuit (influence of a diesel locomotive) [2].

The Pic. 10 shows that the amplitude of voltage of the positive and negative half-waves reaches about 0,5 V, which is more than six times lower than the voltage of reliable attraction of the relay armature (3,2 V) and about four times lower than the voltage of reliable drop-out of the relay armature (2 V). In addition, the interference is of aperiodic nature, which does not create prerequisites for a false relay operation.

Similar results were obtained during the periods the rest of the indicated electric locomotives affected the reference types of track circuits. Thus, it has been established that during the shunt mode of track circuits, the generated interference when lowering and raising the pantograph of electric locomotives does not cause an abnormal activation of the track relay.

Effect No. 3: Shunting insulating joints of two adjacent track circuits when a locomotive/a train moves from one track circuit to another

In this case, when rolling stock moved from a pulse track circuit to the neighbouring one, there was an effect observed, that in the shunt mode the residual voltage at the track receiver had a value other than zero. In this case, clearly distinguishable impulses were detected, albeit with an exceptionally low amplitude (Pics. 10–12). Tested locomotives cannot be a source of this voltage since this effect takes place both in case of a train of two electric locomotives (a tested and an auxiliary one) (Pic. 11), and in case of a diesel locomotive with an electric locomotive coupled to it with a lowered pantograph (Pic. 12).

The oscillogram (Pic. 10) that also recorded that effect, differs, as there were freight cars behind the tested locomotive, during the passage of which through the insulating joints the detected effect did not take place (segment of the oscillogram showing the end of the shunt mode). It also shows that the pulse sequence has the same frequency and pulse duration as the supply voltage of the corresponding track circuits.

The observed effect can be explained as follows. On the one hand, wheelsets of locomotives shunt the rail line on both sides of the insulating joints, which leads to a shunt effect for each of the track circuits. On the other hand, each insulating joint is shunted by the impedance (total resistance) of traction rolling stock and active resistance of the metal structure of rolling stock (both traction and non-traction RS).

To reveal this effect, it is necessary that two adjacent track circuits have opposite ends (receiving end of a TC and feed end of the other TC). In this case, the signal current supply from one track circuit is transferred to the receiving end of the other one. As a result, it was found, as indicated above, that in the shunt mode the residual voltage on the track receiver is not zero, while clearly distinguishable pulses of a characteristic frequency and waveform with low amplitude are observed, which in these cases can be considered as interference.

Oscillograms (Pics. 11, 12) show that the pulse noise has a duration of about 5÷7 s, which is commensurate with time when both locomotives (tested and auxiliary one) cross the zone of insulating joints, i.e., the noises continue until the moment when the previous track circuit (when moving forward) is released by them. The case when the detected interference (Pic. 10) at the end of the shunt mode is followed by a section of the oscillogram without interference, can be explained by passage of freight cars of the train at this time, which suggests that the reason for this interference is associated with the effect of the impedance of locomotives.

Pics. 11, 12 show also that the recorded interference has an amplitude of about 0,5 V, which is ten times lower than the amplitude of the signal current, more than six times lower than the voltage of reliable attraction of the relay armature (3,2 V) and about four times lower than the voltage of the reliable drop-out of the relay armature (2 V). It has been categorically established that this interference does not cause abnormal activation of the track relay during the shunt mode of track circuits.

It should be noted that this effect takes place exclusively in case of pulse, including code, track circuits of 75 and 25 Hz, which can be explained by their principle of operation and their high sensitivity.

4.3. Effect No. 4: Impact of return traction current on impedance bonds

In one's time, when introduction of relay interlocking with AC track circuits began, it was decided that impedance bonds (IB) of DT1-150 type (later of DT0, 2-150, DT0, 6-150 types as well) would be used to pass the return traction current. The power of electric locomotives, even in case of multiple traction, then did not create problems in this regard.

At present, as can be seen from paragraph 3, the situation has changed. Electric locomotives with a capacity of more than 3750 kW with an electric traction of 25 kV create a return traction current of more than 150 A each, that is why, if they are used for multiple traction, there are prerequisites for overheating and even burnout of the traction winding of IB, especially on within the blocks where traffic is organised along the track circuits of the length of about 2000 m.

The solution in that situation is as follows:

- either to prohibit multiple traction of powerful electric locomotives on sections with AC track circuits, which raises objections from the carrier companies,
- or to switch to the use of axle counters, which is happening on the newly modernized sections of the railway, as well as in relay interlocks, whose residual resource is still quite large (ten years or more).

5. Conclusion.

1) Testing of these locomotives has shown that from the point of view of electromagnetic compatibility, none of them can be a source of electromagnetic interference that would have posed a threat to abnormal operation of track circuits used, and hence a threat to safety of train traffic.

2) Even though the part of track circuits listed in introduction to the article was developed in the middle of the last century, and the shorter electronic track circuits were developed in 1970–80s, all types of track circuits used on the railways of Bulgaria turned out to be very resistant to electromagnetic interference emanating from tested models of modern traction rolling stock. This indicates that the methods of protection against the effects of return traction current with a frequency of 50 Hz, chosen in one's time, such as:

- frequency characteristics (signal current frequencies of 75 Hz, 25 Hz, 0 Hz (in some countries), 30 kHz, and others);
- pulse characteristics, including code one;
- phase characteristics,

continue to be relevant and effective today.

3) When using 50 Hz, 25 kV electric locomotives with capacity of more than 3750 kW on the railways of Bulgaria, it is advisable either to prohibit to use them for multiple traction on sections with AC track circuits, or to start using axle counters.

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