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Application of thyristors in railway technology - Measures for the prevention of functional disturbance in signalling installations

Utilisation des thyristors en technique ferroviaire - Dispositions pour éviter les dérangements des installations de signalisation
Verwendung von Thyristoren in der Eisenbahntechnik - Maßnahmen zur Vermeidung von Störungen an signaltechnischen Einrichtungen

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

Leaflet to be classified in Volumes :

V - Rolling Stock

VI - Traction
VII - Way and Works

Application :

With effect from 1 July 1985
For design and construction:
- of traction vehicles used in international traffic,
- of passenger coaches used in international traffic,
- of signalling equipment.
All members of the International Union of Railways

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The person responsible for this leaflet is named in the UIC Code

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Summary

The electrical circuit of a traction current comprises, besides the traction vehicle, the substation, the overhead line, rails, track, ground and often an earth cable and a return conductor.

Signalling installations usually use the track as a transmission medium. It can therefore be exposed to interference, which may result in unsafe operation.

The signalling track circuits may use D.C. (not with D.C. traction) or A.C.

There are A.C. track circuits which operate with 25 - 400 Hz, sine-wave or modulated signal. Also pulsed track circuits, A.C. track circuits at 0,8 - 3 kHz (sine-wave, pulse- or frequency modulated A.C.) or A.C. track circuits at 8 -100 kHz are used.

Axle counters are also used.

Driving cab signalling via track circuits with discontinuous or continuous function exist. Also intermittent train control with resonant systems or carrier frequencies (4,5 - 27 MHz) are used.

In the second half of the leaflet, possible measures to improve the electromagnetic compatibility between the disturbance source and the disturbed object are listed. Measures can be made in the substation, in the track and in the traction vehicle. Also the design of the track circuits are dealt with.

1 - General

1.1 - Field of application

Thyristors are used in the construction of converters which are used:

- on traction vehicles,
- on passenger vehicles, to supply electrical apparatus,
- in traction substations for frequency conversion.

These static converters are sources of harmonics which can disturb signalling systems.

This leaflet is intended to:

- identify the disturbances to which signalling installations are exposed due to the electric traction installations, particularly where thyristors are used,
- set forth remedies and propose recommendations to avoid the disturbances due to this interference.

1.2 - References

This document summarizes in a condensed form, from the signalling installation point of view, the essentiel results given by the work of the ORE Specialists' Committee A 122.

The relevant details are contained in the reports and technical documents published by the ORE[1] Specialists Committee A 122 (see Bibliography - page 14).

1. ORE became ERRI, the European Rail Research Institute in January 1992.

2 - Influence mechanism

2.1 - Physical environment

The electrical circuit of a traction current comprises, in addition to the traction vehicle, the substation, the overhead line, rails, track, ground and, sometimes, an earth cable or a return conductor. The supply of converters on passenger coaches from the traction vehicle is completed through the train line, the vehicles, rails and earth.

Signalling installations use, amongst others, as a transmission medium, the track which then constitutes a link between the traction vehicles and the signalling installations. The latter can therefore be exposed to interference which may result in unsafe operation.

The interference can take place by conductive or inductive coupling. The traction return current flows in the two rails and can achieve excessive values (of amplitude or frequency) and can, in the case of imbalance, circulate undesirably in the signalling circuit. The traction current also creates a magnetic field which can disturb signalling apparatus.

2.2 - Calculation method

Technical Document DT 91 (see Bibliography - page 14) gives a method of calculating the interference developed by electric traction in track circuits.

If the harmonic spectrum of the traction current is measured or calculated (magnitudes of the fundamental wave and its harmonics), it is possible to determine the voltages and currents at the input terminals of the signalling equipment receiver.

The consequences of interference depend on the sensitivity characteristics of the signalling receiver as functions of amplitude, frequency, phase, modulation or coding, noise and the duration of the interference.

NB : A distinction must be made between those effects which are dangerous to safety and those which merely disturb operations.

3 - Possible interference with signalling installations

3.1 - Track circuits

3.1.1 - D.C. track circuits

This type of track circuit must not be used with D.C. traction.

A.C. electric heating of passenger vehicles can generate interference since the current follows the train line and the track between the traction vehicle and the different coaches. In the absence of protection elements across the terminals of the track relay receiver, the track relay can be re-energized by the fundamental of the traction current, the track being occupied.

3.1.2 - A.C. track circuits with frequencies of 25 Hz - 400 Hz

These track circuits are used with both D.C. and A.C traction. With single-rail insulation, the track circuits operate with track transformers and with double-rail insulation, impedance bonds are used. The return current can cause saturation of track transformers and, where there is imbalance of the return current between the two rails, the impedance bonds can be saturated. The voltage of the track circuit is therefore disturbed to the point where the track relay is released so that the track is indicated as "occupied" where in fact it is "free". Interference can also be caused when the operating frequency of the track circuit is equal (or nearly equal) to the frequency of a harmonic of the return current.

Factors which can be the origin or which can influence interference are as follows:

- saturation of track transformers or impedance bonds,
- the proximity of the track circuit operating frequency to a harmonic of the return current,
- return current in the track in D.C. systems,
- amplitudes of the harmonics of the return current,
- receiver sensitivity,
- the type of insulation, whether single or double rail,
- the length of the track circuit,
- the number of parallel tracks and their interlinking (bonding),
- the occurrence of a broken rail,
- leakage asymmetry with double-rail insulation.

3.1.2.1 - Track circuits with sine-wave A.C.

3.1.2.1.1 - With induction relays

The induction relay works with a track signal and an auxiliary signal (auxiliary phase). It can be energized by a signal whose frequency differs from the nominal frequency if this interference signal has sufficient amplitude.

If the track signal frequency differs from the auxiliary signal frequency, the relay indicates "free" and "occupied" at the resultant beat frequency. As the frequency difference increases, the relay indicates only "occupied".

3.1.2.1.2 - With electronic receiver and auxiliary signal

With a small difference between the frequency of the interference signal and the nominal frequency, one observes, as with the induction relay, alternate "free" and "occupied" indications at the beat frequency. As the frequency difference increases, the disturbance is converted into an indication of "occupied".

3.1.2.1.3 - With electronic receiver but without auxiliary signal

After rectification and filtering (possibly amplification), the current from the track is applied to a non-polarised D.C. relay. Safety relies entirely upon the filter. Any disturbance of the track circuit appears as a dangerous condition (untimely re-energization of the track relay).

3.1.2.2 - Track circuits with modulated A.C.

3.1.2.2.1 - With amplitude modulated signals from both track and auxiliary

The frequency and pulse position of the track signal are compared with those of the auxiliary signal, in the receiver.

Interference with this type of track circuit results only in the untimely release of the track relay.

3.1.2.2.2 - With pulse modulated signal without auxiliary signal

The current from the track is evaluated after filtering and decoding.

Safety relies on the filter and decoding. Interference will result only in the untimely release of the track relay.

3.1.3 - Pulsed track circuits

These track circuits, used with both D.C. and A.C. traction, are well suited for use with dirty or rarely used tracks. They cannot usually be disturbed due to the characteristic form of the pulses.

3.1.4 - A.C. track circuits with frequencies of 0,8 kHz to 3 kHz

These track circuits are used with D.C. and A.C. traction; they operate either with insulated joints, with electrically separated joints, sometimes without either. Interference can be caused if the harmonic amplitudes within the pass-band of the receiver become too high.

Factors which can cause or influence interference are:

- the separation between the operating frequency of the track circuit and harmonic frequencies of the return current,
- amplitude of the harmonics of the return current,
- receiver sensitivity,
- type of insulation, whether single or double rail,
- length of track circuit,
- number of parallel tracks and their interlinking (bonding),
- the occurrence of a broken rail,
- leakage asymmetry with double-rail insulation (return-current imbalance).

3.1.4.1 - Track circuits with sine-wave A.C.

The current from the track is evaluated after filtering.

Safety relies on the filter. Interference can have a dangerous effect on safety.

3.1.4.2 - Track circuits with modulated A.C.

The signal used is pulse-modulated or frequency-modulated. The current from the track is evaluated after filtering and decoding. Safety depends on the filter and decoding. Interference results only in the untimely release of the track-relay in the case of imbalance in the return current.

3.1.5 - A.C. track circuits with frequencies between 8 kHz and 100 kHz

These track circuits are used with D.C. and A.C. traction. They operate with insulated joints or with electrically separated joints or with neither.

The current from the track is evaluated after filtering. Safety relies upon the filter.

Interference can be caused:

- by high harmonic currents within the pass-band of the receiver,
- by the occurrence of a broken rail.

3.2 - Axle counters

3.2.1 - Axle counters with magnetic detectors and electromechanical counters

Disturbance can be produced by leakage fields from inductors on locomotives if these are mounted close to the rail.

3.2.2 - Axle counters with electronic sensors and electronic or electromechanical counters

Disturbances can be caused by induction:

- if the fundamental of the return current reaches high values in a rail,
- if the harmonics near the operating frequency of the counter reach dangerous values,
- if the inductors on the traction vehicles are mounted close to the rail.

3.3 - Driving cab signalling via track circuits

Concerning their track circuit function, cab signalling systems using track circuits are subject in principle to the same risk of disturbance as the track circuits used in conventional signalling systems. For transmission from track to train, since the information is transmitted in pulse form or as a frequency modulation of a carrier frequency, disturbances cannot be converted into unsafe states, taking into account the decoding circuits.

Disturbances causing operating difficulties can be produced if the signal-to-noise ratio is not sufficient.

3.4 - Driving cab signalling with continuous track conductors

Driving cab signalling systems which use track conductors are subject to interference which is coupled inductively from the traction current circuit into the receiver on the traction vehicle or the lineside equipment. Disturbances transmitted from the track conductor to the vehicle receiver can be disregarded.

Studies have shown that the bit error rate in coded transmissions with thyristor traction is similar to that obtained with direct motor control.

3.5 - Intermittent train control

3.5.1 - Resonant systems (for example 500, 1000, 2000 Hz)

When the limit conditions of the system are observed, these installations are to a large extent insensitive to disturbances developed by the traction current circuit.

The magnetic noise field parallel to the rails between the track transmitter and the vehicle receiver must be limited, depending on the type of system.

The transverse voltage induced in the supply cable must also be limited.

3.5.2 - Systems with carrier frequencies of 4,5 MHz to 27 MHz

In this frequency range, interference appears only as low-amplitude pulses. A digital transmission which is coded and has redundancy, with multiple repetition, gives a sufficient security against interference from the traction current circuit.

4 - Possible measures to improve the electromagnetic compatibility between the disturbance source and the disturbed object

4.1 - Substation, overhead line, return circuit

With D.C. traction lines, the rectifier voltage harmonics can be reduced by installing filters and smoothing circuits in the substation.

Resonant overvoltages which appear in the line can be reduced by installing RLC elements in the overhead system.

The value of return current in each rail can be reduced by arranging close bonding between parallel tracks. Reduction of the distance between substations will contribute to a reduction of induced voltage in nearby signalling installations.

On A.C. lines, reduction of induced voltage in nearby circuits can be obtained by the following methods: earth wire and supplementary compensation conductor, supply systems using auto-transformers or using booster transformers and return conductors.

4.2 - Traction vehicle

4.2.1 - D.C. traction vehicles with thyristor control

- Chopper control frequencies must be chosen which are outside the range of frequencies in signalling installations.
- This problem is generally simplified by the use of fixed chopper frequencies, or preferably by one single frequency.
- To avoid resonances, capacitive equipment should not be used for protection against overvoltages.
- The input filter should be designed to prevent undesirable harmonics.

4.2.2 - A.C. traction vehicle with thyristor control

The power circuit must be designed to prevent the generation of an undesirable level of disturbing harmonics. It could, for example, include filters. Firing angle asymmetry in the current wave form taken from the catenary must be limited.

4.3 - Converter to supply the train line and converters on passenger coaches

The converters and their filters must be designed so that the current drawn does not contain harmonic disturbances in the frequency bands used by signalling equipment.

NB : concerning points 4.1 to 4.3:
It is necessary to ensure that the electromagnetic field radiated by traction vehicles or by converters on coaches does not disturb signalling equipment.
It may be necessary to provide special equipment to monitor certain harmonics (amplitude, duration) or firing angle asymmetry. In this case, it is recommended that the "fail-safe" concept be used in the design.

4.4 - Track circuits

4.4.1 - Choice of operating frequency

It is appropriate to choose, for the operating frequencies of track circuit installations, frequencies which differ from the fundamental and harmonics of the traction current, particularly the odd harmonics.

This condition must take account of the following:

- the spectrum of the traction current is largely determined by the type of electric traction vehicle,

- the use of thyristors to regulate electric traction vehicles can generate, in the traction current, frequencies which are Indirectly related to the fundamental frequency, due to inter-modulation,

- the effects of resonant frequencies in the traction circuit are not known in advance.

One remedy is a fundamental separation of the frequency ranges for electric traction and for signalling installations, taking account of the permissible tolerances of the harmonic frequencies of the traction return current and of the pass-bands of the track circuits.

4.4.2 - Measures to be taken on the track

Whether the track circuits use single or double rail insulation, all metal connections with the traction current return path (for example, the longitudinal connections of the impedance bonds or the connection between the impedance bonds and rail), as well as track inter-connections (e.g. the cross-connections between impedance bonds or between rails), must be regularly examined to limit voltage drops and potential differences.

4.4.3 - Permissible amplitude of the disturbance signal and its harmonics

4.4.3.1 - Definitions

To ensure the operation of a track circuit protected from disturbance, it is necessary that the components of the disturbing signal which fall within the pass-band of the track circuit receiver, should not exceed permissible limit values. To determine the permissible limit values of disturbing currents, it is necessary to consider the most unfavourable conditions for the creation of maximum disturbance in the signalling installations, notably the maximum length of the track circuit, due to the high sensitivity of the receiver and the low level of the useful signal

with:

with:	fo	=	nominal frequency of the track circuit,
	$A_e(fo)$	=	amplitude of the useful signal, at the nominal frequency, which is necessary to pick up the receiver (threshold value),
	$A_c(fo)$	=	amplitude of the useful signal, at the nominal frequency, at which the receiver releases,
	A_{pm}	=	measured amplitude of the disturbance signal which causes the receiver to drop out (for example, by saturation of the transformer or masking of the useful signal),
	$A_p(fo)$	=	amplitude of the components of the disturbing signal which are situated in the pass-band of the receiver,
	A_p	=	effective value of the disturbing signal,
	A_{res}	=	residual maximum amplitude of the useful signal at the terminals of the receiver with the track occupied,
	S_1, S_2, S_3	=	safety coefficients.

4.4.3.2 - Prevention of untimely re-energisation of the receiver

With the track occupied, the useful signal at the terminals of the receiver is equal to the residual voltage A_{res}. The receiver must not be energized. We should thus have:

$$A_p(fo) < A_e(fo) - A_{res}$$

i.e.: $$A_p(fo) \leq \frac{A_e(fo) - A_{res}}{S_1}$$

4.4.3.3 - Prevention of untimely maintenance of the receiver in an energized position

The track being free, the receiver must drop out when the track circuit is shunted. It is then necessary to have:

$$A_p(fo) < A_c(fo) - A_{res}$$

i.e.: $$A_p(fo) \leq \frac{A_c(fo) - A_{res}}{S_2}$$

4.4.3.4 - Prevention of untimely drop-out of the receiver

The track being free, a useful signal and a disturbing signal are present. The receiver is subjected to the disturbing signal. To maintain the receiver energized, it is necessary that:

$$A_p < A_{pm}$$

i.e.:

$$A_p \leq \frac{A_{pm}}{S_3}$$

4.4.3.5 - Safety factor

To satisfy the conditions in points 4.4.3.2 - page 10, 4.4.3.3 - page 10 and 4.4.3.4, a safety coefficient must be chosen as indicated (S_1, S_2, S_3).

It is recommended that the probability of the appearance of the maximum disturbing signal be taken into account.

NB : The following safety factors, for instance, are recommended:

$S_1 = 3$ $S_2 = 2$ $1 < S_3 < 2$

For example, certain track circuits cannot be re-energized by a disturbing signal; in this case, point 4.4.3.4 only need be satisfied.

The permissible maximum value of disturbance $A_p(fo)$ can be exceeded for a short time.

The permissible amount of time during which this may occur must be fixed by the different railways, taking into account the individual characteristics of their different track circuits and associated systems.

4.4.4 - Individual measures

4.4.4.1 - D.C. track circuits

- The track relay can be protected against current developed at the fundamental frequency with the aid of series chokes as well as the self inductance of the relay. These chokes also protect the track relay against currents at higher frequencies.
- The maximum amplitude of traction current in a relay should be limited to a fraction (for example, one third) of the value capable of re-energizing the relay.
- Other measures: Increase of the activation time of the track relay, coding of the direct current and addition of a resistance in the relay circuit.

4.4.4.2 - A.C. track circuits with frequencies between 25 Hz and 400 Hz

Damping resistances can be installed to reduce the proportion of return current which passes through the track coils of the track transformers. Certain harmonics can be reduced by the use of suppression filters.

If air gaps are used in the magnetic circuits of track choke coils or track transformers, saturation does not occur until increased values of traction current are flowing.

4.4.4.3 - Pulsed track circuits

In the receiver: use equipment to limit overvoltages. Provide activation time delay between the receiver and the relay.

4.4.4.4 - A.C. track circuits with frequencies between 0,8 kHz and 3 kHz

The operating frequency of the track circuit should be chosen to provide an adequate separation between the operating frequency and the disturbing harmonics.

Improvement of filters.

Use of a modulated working signal and the installation of a safety decoder in the receiver.

4.4.4.5 - A.C. track circuits with frequencies between 8 kHz and 100 kHz

If necessary, a modulated signal can be used with a safety decoder in the receiver.

4.5 - Axle counters

The disturbances which have been observed in axle counters using electronic sensors with traction return currents greater than 400 A at 16 2/3 Hz can be eliminated by placing a metallic conductor of sufficient section in parallel with the rail.

4.6 - Driving cab signalling systems

4.6.1 - Signalling using track circuits

The following cases can exist:

4.6.1.1 - In addition to the useful modulated signal, there is a permanent disturbing signal. To obtain good operation of the receiver, the following conditions must be met:

$$A_p < A_s$$

i.e.: $A_p \cdot s \leq A_s$

The safety factor which is recommended is:

$$1 < s < 2$$

with: A_s = amplitude of the component of the disturbing signal, at the same frequency as the carrier of the useful signal, which causes the receiver to release.

A_p = amplitude of the component of the admissible disturbing signal, at the same frequency as the carrier of the useful signal at the terminal of the receiver.

4.6.1.2 - In the absence of a useful modulated signal, the disturbing signal must not be confused by the receiver with a useful signal. This is achieved by appropriate modulation or coding of the useful signal.

Further measures:

- It is preferable to use double-rail insulated track circuits, with double connection to the rail, to obtain as low an electric resistance as possible and to avoid the effects of breakage. These connections must be regularly examined.
- The carrier frequency of the track circuit should be chosen to give a sufficient frequency separation from the disturbing harmonics.
- In the case of amplitude modulation. the modulation frequencies of the track circuit must be chosen to obtain a sufficient frequency separation from the beat frequency between two adjacent frequencies of the traction current.

4.6.2 - Driving cab signalling using track conductors

For transmission from track to train, a ratio of at most 15 dB should be provided between the useful field produced by the minimum current circulating in the track conductor and the maximum value of the disturbing field, for a maximum spacing of 500 mm between the upper surface of the rail and the receiver on the vehicle; for both short loops (0,3 km) and long loops (6 km).

For transmission from train to track with short loops (0,3 km), a ratio of 15 dB should be provided between useful signal and disturbing signal. With long loops (6 km), it is necessary to add an attenuation of about 3,5 dB per km. The signal-to-noise ratio must then achieve a value of 36 dB.

The disturbance signals produced by the traction vehicle can be reduced by careful design and installation of the earth connections between the electrical equipment on the one hand, and the metal of body and bogies on the other.

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