HOW TO REDUCE THE IMPACT OF TRACK CIRCUIT FAILURES

Stanislas Pinte, Maurizio Palumbo, Emmanuel Fernandes, Robert Grant
ERTMS Solutions/NxGen Rail Services

Summary

Every year, thousands of track circuit failures are reported by railway infrastructure managers in Europe and worldwide, resulting in significant delays which can also lead to substantial economic costs and penalties.
For this reason, the ability to detect and diagnose the health of track circuits to prevent or provide a fast response to these failures, can generate a significant benefit for infrastructure managers.

In many countries, a process of periodic manual inspection of wayside assets (including track circuits) is in place, but the benefits of this strategy are limited by several factors related to safety, the time required to perform the inspection, and difficulties associated with making manual measurements.
With the purpose of minimizing economic loss and operational delay, as well as offering railway infrastructure managers a tool that can provide an automated and effective maintenance strategy, ERTMS Solutions has designed the *TrackCircuitLifeCheck* (TLC).

The *TrackCircuitLifeCheck* is a track circuit measurement instrument that can be installed on track inspection or commercial trains to automatically diagnose AC, DC, and pulsed track circuits, thus enabling a preventive maintenance strategy, based on the analysis of multi-pass data from each track circuit over time, and the application of standard deviation analysis.

KEYWORDS: Track Circuits, Preventive Maintenance, Train Detection, Train Protection, In-Cab Signaling, UM-71, TVM, *TrackCircuitLifeCheck*.

INTRODUCTION

In order to detect the presence of trains on a railway network, railway tracks are divided into blocks of varying length. These are separated from each other by means of a physical (or electrical) separator called a *joint*.

A track circuit is an electrical device (powered by an AC or DC source) which is used to detect the presence of a train on any one single block and, optionally, to transmit information to the on-board system for the purpose of controlling the train's speed.

Because they are a safety-critical asset, track circuits need to be fail-safe; therefore, a failure in a track circuit will result in the block being indicated as occupied to eliminate the possibility of an accidental collision. Though this is a necessary safety feature, it can have a severe impact on track availability and service operations.

With an average failure rate of around 45% per year per track circuit, railway infrastructure managers have a strong incentive to implement an effective maintenance strategy for track circuits that prevents failures from happening.

This paper presents a high level functional and architectural description of track circuits, with a special focus on AC track circuits. It will also introduce a real case study (UM-71 and TVM technologies) with the aim of presenting an innovative maintenance solution.
As a conclusion, we will show the advantages of using an automated maintenance tool for track circuit condition monitoring and we will suggest the requirements for a tool that can meet this need adequately.

Notation

AC	Alternating Current
BSP	Boucles à Saut de Phase
DC	Direct Current
EPI	Emetteur Ponctuel d'Information
FSK	Frequency Shift Keying
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LC	Inductor-Capacitor Network
MTIE	Maximum Time Interval Error
JES	Joint Electrique de Séparation
OBU	On-Board Unit
TLC	Track Circuit Life Check
TVM	Transmission Voie Machine

1. WHAT IS A TRACK CIRCUIT?

A track circuit is an electrical device used to detect the absence of a train on one single segment or block of track.

1.1 Train detection

The operational principle of a track circuit is based on an electrical signal transmitted between the two running rails. The presence of a train is detected by the electrical connection between the rails, conducted through the wheels and the axles of the train.

When no train is present, the current supplied by the power source is transmitted by the running rails to the relay and the track circuit is unoccupied.

When a train enters the block, its front wheels and axles connect the two running rails together shorting the power source and thereby reducing to zero the current flowing through the relay. This causes the relay to "drop" (Figure 1), turning off the green signal light and turning on the red light to indicate that the block is occupied by a train.

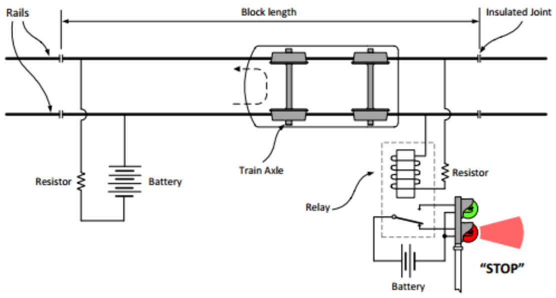

Figure 1: Track Circuit

It is worth mentioning that the longer the track circuit, the greater the physical distance between the power source and the relay (or the train's leading axle).

Due to the resistive characteristics of the rail and to the low conductivity through the ballast between rails, this distance usually causes a signal attenuation that can lead to a wrong, or at least poor, current measurement.

Given the serious consequences of this attenuation, many AC track circuits are equipped with *compensation capacitors,* placed between the circuit's edges, with the purpose of periodically boosting the generated current (this is the case for the CSEE/ANSALDO UM-71C track circuit technology).

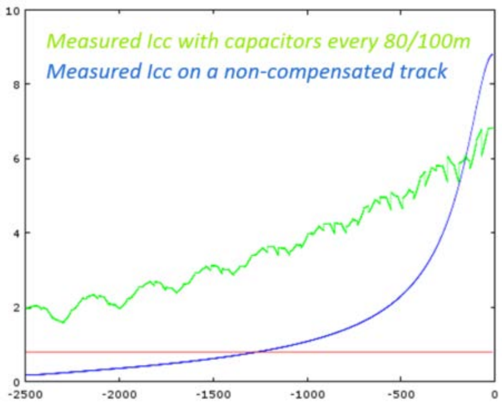

Figure 2: Shunted Current diagram with and without compensating capacitors

1.2 Train Protection

Coded track circuits are inductive systems that use the running rails as a trackside-onboard information transmitter.

Alternative means of transmitting information from wayside to the train are inductive loops, that use a changing magnetic field to transmit information to the train.

The on-board system interprets the decoded command with the aim of controlling the speed of the train and implementing an "In-Cab" signaling system for train protection.

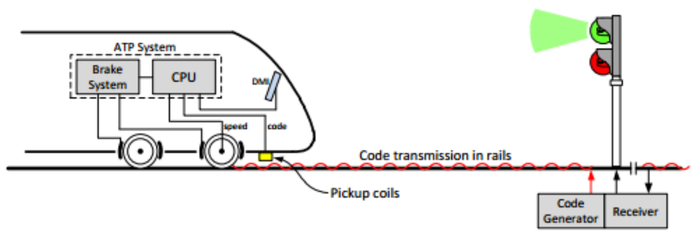

Figure 3: In-Cab Signaling System

2. CLASSIFICATION

2.1 Power Supply

Depending on the nature of the current generated by the Track Circuit voltage source, track circuits can be classified as DC (Direct Current), first generation of track circuits, AC (Alternative Current), and pulsed track circuits, which operate by applying a short high voltage pulse to the rails at relatively long intervals.

In a DC track circuit, the signal source is generated by a direct current coming from a battery or an AC signal rectifier, connected to the rails at one edge of the block section.

AC track circuits are energized by an alternating electrical current with a frequency ranging from 50 Hz up to 10 kHz (the range of Audio

Frequencies), to avoid interference from the 50Hz traction current.

Excepting for the type of current and apparatus used, the AC and DC track circuits are similar in operation, although AC circuits are progressively replacing the older DC ones due to improved robustness, reliability, and more efficient track-to-train data transmission.

2.2 Block Separation Technology

For detecting the presence of any trains along a railway network, railway tracks are divided into blocks of varying length, separated from each other by means of a physical (or electrical) separator called a *joint*.

Originally, when just the DC track circuits were available, this separation was realized by cutting one rail and inserting an *insulated joint* whereas the other rail used to remain continuous to handle the traction power return (in the case of electrified track).

Figure 4: Insulated track joint

By moving from direct current to alternating current circuits, the blocks have been divided by means of electrical joints made of tuned LC circuits (consisting of an inductor L, and a capacitor C, connected together for generating signals at a particular frequency) avoiding the need for insulated joints. These are called *jointless track circuits*.

3. A CASE STUDY: CSEE/ANSALDO UM-71 and TVM

3.1 Track Circuit UM-71

The UM-71 from CSEE/ANSALDO is a jointless AC Audio Frequency track circuit, which divides the track into *electrical segments*, using different carrier frequencies.

Four frequencies are used for the carriers (from 1700Hz to 2600Hz) and each carrier is frequency modulated by a sinusoidal signal.

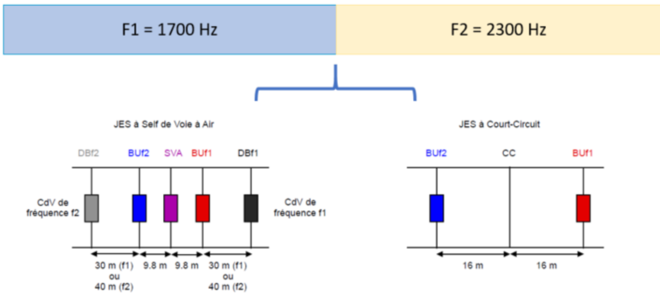

Figure 5: UM-71 frequency-based track separation

The JES (*Joint Electrique de Séparation)* electrical joint between two sections is achieved by electrical impedances (see Figure 5, above).

3.2 In-Cab Signaling TVM

The TVM (Transmission Voie-Machine) is an In-Cab signaling system originally deployed in France and implemented on the top of UM-71 track circuits.

The information from track to train is transmitted either:

- continuously, at any time when the train occupies the section, by modulating the AC track circuit carrier frequency with some bits (from b_0 to b_{27}) of information present in the modulating signal as very low frequencies, and each bin in the spectrum representing each different bit. Every 28-bit word has a specific signaling meaning that the train driver, as well as the on-board system, will need to process to ensure a safe journey.

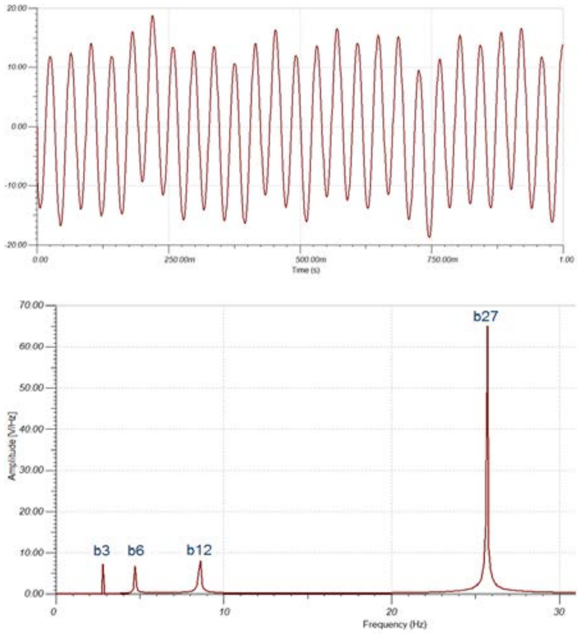

Figure 6: Modulating signal and its spectrum showing the presence of bits

or

- pointwise, by using electrically independent active loops called BSP *(Boucles à Saut de Phase,* for TVM-430) and EPI (*Emetteur Ponctuel d'Information*, for TVM-300). These loops are able to send data to the on-board system, taking advantage of the changing magnetic field created by AC currents in the loops.

4. FAILURES OF TRACK CIRCUITS

A failure is an (unwanted) event on a technology-based system that compromises its ability to operate correctly.

A track circuit is a safety-critical asset; therefore, it is designed to be fail-safe.

A fail-safe in engineering is a design feature or practice that in the event of a specific type of failure, inherently responds in a way that will minimize or eliminate the possibility of harm to other equipment, the environment, or to people.

This means that a failure in a track circuit will result in it being shown as occupied, regardless of whether or not this is actually the case, as the status of the block in question is uncertain. This has a significant impact on track availability and day-to-day operations.

Given the gravity of a track circuit failure, the next question is: *how often does it fail*?

Track Circuit	Number	Failures per year	Failure rate	Delay impact (min)
AC TC	3643	1264	0.347	158000
TI21	1326	524	0.395	65500
FS2600	528	241	0.456	30125
HVI TC	952	390	0.410	48750
Reed TC	1895	1304	0.668	163000
Overall	8344	3723	0.446	465375

Table 1: Track Circuit failure rates in the UK

According to a recent study "Condition Monitoring of Audio Frequency Track Circuits - [4] " by the University of Railway Engineering of Birmingham, there are nearly 80,000 track circuits in operation on the mainline railway network within the UK. Table 1 shows the number of track circuits installed in Network Rail's Southern Zone together with typical failure statistics.

The average failure rate is around 45% per year per installation, and any track circuit failure can cause significant disruption to rail services.

Over 12,000 track circuit failures were reported in the UK during one operational year, resulting in 1.5 million minutes of delay. Typically, the infrastructure operators are penalized by £20–£60 per delay minute arising from infrastructure failure, but in the case of a heavily used network section, this can go up to £250 per delay minute. Therefore, the ability to detect and diagnose track circuit failures to provide a fast response to failures/incidents has a significant economic benefit.

4.1 Failure Modes

A "failure mode" is a way in which a technology based system (like a track circuit, in this case) might fail.

Given the high frequency and heavy impact of track circuit failures, it is of interest to assess the causes of these failures.

There can be many reasons for a track circuit failure, so key measurement parameters need to be constantly monitored to minimize the probability of these failures.

Although it is almost impossible to document every type of track circuit failure, the following are the most common types of failures which may occur over the life of a track circuit.

The following failure examples can be critical either in terms of availability and/or safety.

4.1.1 Shunt Failure

A Shunt Failure (safety critical) occurs when the short circuit current cannot be measured

correctly; therefore, the device is not able to perform its main function.
This type of failure might occur for a number of different reasons. For example, a broken or oxidized rail, or a failure in transverse impedances (for TC equipped with electrical joints) are among some of the most frequent causes of shunt failure.

4.1.2 Frequency Drift

Frequency drifting is an unintended and generally arbitrary offset of an oscillator from its nominal frequency, due to component aging, changes in temperature, or problems with the voltage transmitter.

It is a common problem in AC Audio Frequency track circuits, since it impairs the correct operation of all frequency tuned elements, creating track availability issues.

4.1.3 Leaking Electrical Joints (Tuning Units)

In the case of jointless AC track circuits, one of the most common failures takes place in electrical joint components, such as the LC tuned passive components which are affected by drifting capacitance.

The tuned LC components fail to properly filter and separate adjacent frequencies from the side segment, producing a leak (also known as *longitudinal crosstalk*) from one track circuit segment to another.

This can severely impair the correct detection of the train, causing the segment to look occupied when it is not.

5. MAINTENANCE OF AC TRACK CIRCUITS

5.1 Manual Inspections

Due to the significant impact of track circuit failures, railway infrastructure managers are required to implement an effective maintenance strategy.

For this reason, periodical TC manual inspections are in place to minimize economic loss and operational delays. This is done by using the following portable test equipment:

- multi-meter and AC probes, able to measure the voltage and c of the devices mounted along the track
- frequency counter, able to measure frequencies

However, a number of important limitations clearly affects this approach:

- Sending teams onto the tracks significantly increases the safety risks associated with inspection.
- The number of track circuits measurable per inspection is quite low.
- It's very labor-intensive, and therefore costly.
- Manual measurements are error-prone. They can only detect a limited range of failure modes, which makes them an unpractical and costly approach to TC maintenance.

5.2 TC Remote Condition Monitoring

Remote Condition Monitoring (RCM) is the process of monitoring a number of parameters in a device, in order to identify any significant changes which may indicate that a fault is developing.
In the case of track circuits, a common form of RCM is to constantly measure the current levels at the track circuit receiver for free and occupied segments. Unfortunately, this cannot guarantee a preventative approach, because the relationship between the Track Circuit parameters along the track and the current value at the receiver and transmitter ends is not linear. This means that they are not good indicators of a potential failure.

5.3 Key Parameters

To be defined as comprehensive and effective, each measurement session should be able to detect and assess the quality of the following parameters:

- Icc (shunt current) levels for each relevant frequency
- transversal elements (electrical joints)
- compensating capacitors, if present, along the track
- data transmission modulation and verification for both pointwise and continuously transmitted data.

6. THE TRACKCIRCUITLIFECHECK

The *TrackCircuitLifeCheck* (TLC) is a track circuit measurement instrument that can be installed on track inspection or commercial trains.

It performs an automatic diagnosis of AC and DC track circuits, allowing its users to adopt a true preventive maintenance approach.

The *TrackCircuitLifeCheck* is designed and manufactured at ERTMS Solutions. Its modular design allows it to be configured to accommodate whatever mix of Track Circuit types need to be measured for each customer.

Figure 7: ERTMS Solutions TLC On-board rack

6.1 UM-71 and TVM maintenance: the *TLC/UM-71*

A customized version of the *TrackCircuitLifeCheck* has been supplied to French/UK railway lines to enable preventative maintenance of UM-71C track circuits and TVM In-Cab signaling systems.

The *TVMLifeCheck* is able to:

- highly reduce the safety risk associated with manual inspections.
- measure hundreds of track circuits per hour.
- ensure real-time TC (TVM-300 and TVM-430) analysis during each train journey.
- measure currents and audio frequencies (1700, 2300, 2000 and 2600 Hz) with a +- 1 Hz precision.
- measure shunted track circuit currents |Icc|.
- detect and measure the quality of transverse impedances (electrical joints).
- detect and measure quality of transmission line compensation capacitors.
- detect and measure quality of the FM modulation for track-to-train transmitted bits detection.
- send real-time alarms to Traffic Control Centers over GSM/GPRS network.

Figure 8: *TLC/UM-71* Antenna for Eurotunnel

Once data has been collected, analysis can be carried out to determine whether the track circuits are working correctly.

6.2 Case Study: TLC in operation at EUROTUNNEL

After one year of operation of the TrackCircuitLifeCheck, Eurotunnel has been able to reduce Track Circuit Failures by 25%.

The remaining failures cannot be detected by an onboard measurement instrument, as they are either instantaneous or they occur on the trackside, which means that they are not producing anything measurable.

CONCLUSIONS &/or RECOMMENDATIONS

Condition monitoring of track circuits is a vital aspect of railway operation and there are several types of maintenance systems available on the market.
The following table lists the ones described above, as well as the type of maintenance strategy they enable.

TC monitoring system	Characteristics
Manual Inspection	Corrective maintenance only Low measurements accuracy Very slow maintenance process Trackside personnel required Safety hazard Continuous TC monitoring not possible
RCM	Corrective maintenance Unpractical for preventive maintenance Continuous TC monitoring partially available Frequency drift, Leaking and crosstalk information not detectable Needs a large quantity of trackside measurement equipment
Onboard Track Circuit measurement instrument (TLC)	Enables preventive maintenance High measurement accuracy Key TC parameters measurements No trackside measurement equipment required On-board automatic maintenance Continuous TC monitoring capability

Table 1: Failure modes detection of TC monitoring systems

Although manual inspections or remote condition monitoring solutions can help minimize the economic loss and operational delays caused by track circuit failures, these approaches can be significantly improved.
Using an automated onboard maintenance tool able to perform an effective and comprehensive measurement set enables railway infrastructure managers to answer this need adequately.

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