Investigation of shunt operation performance of jointless track circuits using a specialised track circuit computer simulation tool

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Abstract

Compared to the conventional jointed track circuits the train detection performance of modern audio frequency jointless track circuits (AF JTC) presents some deficiencies in the form of discontinuities, zones of train detection ambiguity, lack of strict boundaries, etc. The detailed knowledge of the shunt performance of JTCs is essential for ensuring their correct implementation in the overall signalling system design. This paper is concerned with the investigation of the train detection performance of FS 2000 jointless track circuit. It defines the purpose of the study, briefly outlines the basic features of the specialised computer program for track circuit modelling and simulation used for the investigation and presents the results of the computer simulations.

Introduction

Track circuits (TCs) are used in signalling systems to provide positive information about the absence of a train on a rail track section. As a vital function it is required that the train detection function is implemented on the basis of the fail-safe principle. In addition, it is highly desirable, although not absolute, that the information provided by a TC is continuous and unambiguous. The first implies that a track circuit should be able to detect a train at any point of its length. The second requires that a TC should only detect a train if it is present within its boundaries. These requirements can be fully achieved only with jointed TCs which operate as independent systems each
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Confined to its physical section of track. Contrary, AF JTC have no physical insulation between them and are being separated ‘electrically’ by specially designed electric circuits - electrical separating joints (ESJs) or with no separation at all. Because of this and the particular design of the TC terminations the train detection performance of AF JTCs may differ from the ideal continuous and unambiguous shunt performance in a number of ways. Depending on the specific design of the ESJs (whenever such are used) and the type and positions of coupling of TC transmitter and receiver these deficiencies can take the form of ‘dead’ zones of no train detection, zones of train detection ambiguity, zones of pre- and/or post-shunting, interference between the operation of adjacent track circuits, etc. [1]. To overcome these deficiencies on a system level a detailed knowledge of the train detection performance is necessary.

Tasks of the investigation of the train detection performance

The first task of the investigation of the performance of a particular TC design is to determine its definition area. This includes the identification of the sets of physical variables describing TC design parameters, the full range of operating conditions and the effect of the environmental factors together with their definition intervals . [5]. Then the purpose of the study is to demonstrate that the TC under consideration performs correctly in any point of the definition area. This can be achieved by investigating what parameters and operating conditions affect TC shunt performance, and more particularly those which deteriorate the shunt sensitivity. The analysis of the results obtained should enable to define the worst TC shunt operation scenario.

Method and tools for the investigation

The shunt operation performance of conventional bounded track circuits is well investigated by analytical methods [2]. Jointless track circuits are more complex, involving a higher number of design and operational parameters. Because of the electrical and functional connection between them they cannot be studied in isolation but as a system of at least two adjacent TCs which adds to the complexity of the problem. Taking account of the wide area of operational conditions for which the performance has to be studied it is clear that the most efficient method of investigation is by computer simulations of TC operation on the basis of a realistic and validated TC model. This study of TC operation is carried out using a specially developed computer program for TC modelling and simulation. (More details can be found in [4] and [5].

Computer simulations and results
It has been considered most efficient to carry out dynamic simulations of a train shunt moving along three consecutive track circuits, starting in TC K, at some distance e.g. 30 m from TC Y receiving end and finishing in TC X, at some distance after TC Y transmitting end. Such a single simulation provides information allowing to study different aspects of track circuit operation, namely:

- Distribution of the shunt sensitivity along the track circuit
- The mechanism of train detection and the processes happening at TC interfaces when train shunt enters the receiving end and leaves the TC at the transmitting end
- Proximity effects e.g. effect of a train shunt on an adjacent track circuit close to the transmitting or receiving end.
- Allows to investigate in parallel both the unshunted and the shunted operation and compare the effects of different factors on the two operating modes simultaneously.

Dynamic simulations have been carried out to establish the effect of various parameters on track circuit performance - rail track parameters, track circuit design and operational parameters. The TC performance is assessed by the current in TC receiver although other criteria can also be used.

**Investigation of the mechanism of train shunt detection in JTCs (Figs.1-4, 15)**

In general the graphs of the currents and voltages in the rails and in TC receiver resemble those of a bounded TC in that they demonstrate the typical abrupt changes when the shunt enters and leaves the track circuit. However, there are some differences due to the way the train shunt affects the TC.

In bounded track circuits a train shunt shortens the rails causing a substantial increase of the TC current. As a result the electrical energy delivered by the transmitter is being absorbed mainly by the feed impedance while the energy delivered into the rails is insufficient for the energisation of TC receiver. In more complicated bounded track circuits, e.g. AC TCs with double element vane relay receivers, the shunt acts simultaneously by decreasing the amplitude of the signal in the receiver and disturbing the phase relationship between the signal coming from the rails and a local reference signal.

In jointless TCs the mechanism by which the train shunt causes the de-energisation of the receiver depends on the particular design of track circuit terminations. The terminations of FS 2500 track circuit represent specially tuned circuits and the train shunt has the effect of de-tuning those circuits thus disabling the transfer of the energy required for the energisation of the receiver. The de-tuning effects of the train shunt starts at some distance before the points of connection of TC equipment. In TC receiving end the effect of the train shunt is ‘masked’ by the low impedance terminating bonds and starts to be felt only in the area between the terminating bonds and the points of connection of TC receiver tuning unit. The train detection takes place somewhere in this area as a result of the resonance conditions becoming disturbed and the fast decrease of
FIG. 5 Effect of rail track resistance on train detection performance

FIG. 6 Effect of rail track inductance on train detection performance

FIG. 7 Effect of rail track conductance on train detection performance

FIG. 8 Effect of rail track capacitance on train detection performance
FIG. 9 Effect of track circuit length on train detection performance

FIG. 10 Effect of TC cable length on train detection performance

FIG. 11 Effect of TC transmitter internal resistance on train detection performance

FIG. 12 Effect of TC receiver resistance on train detection performance
the current in TC receiver (IR5 in Fig.2). The current in the rails (IR4) remains high until the shunt passes the tuning unit connection points where it reduces stepwise to a low level, similarly to what happens in bounded TCs. In TC receiving end the train shunt effect is particularly pronounced and demonstrates at about 40-45 m before the points of connection of TC transmitter by the dramatic changes in the currents and voltages in TC transmitting end (Figs.1 and 3). In the inner part of the TC where the presence of the train shunt does not affect the tuning of the TC terminations a train is being detected by the shunting effect of its low ohmic axles as this takes place in bounded TCs.

Investigation of the effect of rail track parameters (Figs.5-8)
The simulations show that for the specified ranges of variation of rail track parameters which are wide enough to cover all expected operational conditions the track circuit has correct shunt performance with a vast amount of reserve. The shunt sensitivity decreases with the increase of rail track resistance and conductance and with the reduction of rail track conductance. The variation of rail track inductance demonstrates a well expressed minimum of train shunt sensitivity (the current in TC receiver reaches maximum) at the value for which the TC track circuit terminations have been tuned. The variation of rail track conductance causes only a small variation of the level of the current in TC receiver. This is explained with the fact that this parameter has little effect on the tuning of track circuit terminations. In the same time, the variation of the resistance and the inductance causes a wide spread of the level of the current in TC receiver. While in shunt operation its value remains below the level of de-energisation of TC receiver, for higher resistances and for inductances at the borders of the range of variation the unshunted operation is no longer provided. This points out the necessity of adjusting the TC design according to the values of TC resistance and inductance on the particular railway. It is important to note that the variation of these two parameters causes also changes in the distribution of train shunt sensitivity along the track circuit. The maximum always remains in the middle of the track circuit but what is more important, for extreme values of rail track resistance and inductance the minimums of shunt sensitivity are shifted away from the points of connection of TC equipment towards TC centre.

Investigation of the effect of track circuit operational parameters (Figs.9-12)
The simulations of TC shunt operation with variation of TC operational parameters indicate that the ohmic resistances of TC transmitter and receiver have very little effect both on the shunted and unshunted operation. The distance between the TC and the equipment room where the TC equipment is installed has insignificant effect compared to the other parameters. The most critical parameter is the TC length. The variation of this parameter causes changes both in the level and the distribution of train shunt sensitivity. The shorter the track circuit, the lower the shunt sensitivity and the higher the step change of the signal in TC receiver when a shunt enters or leaves the TC. This
indicates the need for an individual adjustment of the level of the signal of TC transmitter according to the TC length. When determining the worst operational scenario of shunt operation it is necessary to take into consideration that in shorter TCs the minimum of train shunt sensitivity may appears in the middle of the TC instead of the TC ends. This is explained with the fact that in shorter track circuits the distance from a TC termination at which the train shunt starts to have visible effect on the tuning becomes comparable with the track circuit length.

Determination of the worst scenario of shunt operation and the values of the critical parameters (Figs. 14-16)
The ultimate aim of the investigation of TC shunt operation is to establish the worst scenario of operation i.e. the set of critical values parameters which yield the worst train shunt sensitivity. On the assumption that the TC parameters are suitably adjusted for the particular values of rail track resistance, inductance and TC length, the two critical parameters which affect the train shunt operation are the rail track conductance and the train shunt resistance. The simulations illustrated in Fig. 14 confirm that in the area of minimum train shunt sensitivity (15-20 meters before the point of connection of TC receiver) train shunts up to 0.8 Ohm are reliably detected even for the lowest values of rail track conductance. Fig. 15 shows that with the increase of train shunt resistance and rail track conductance the train shunt position of minimum shunt sensitivity shifts away from the TC end.

Another aspect of the shunt operation performance of FS 2500 TC is the presence of zones of no shunt sensitivity. They are located at track circuit terminations and depend mainly on train shunt resistance (Fig. 16). The higher the train shunt resistance, the wider the zones where the train remains undetected.

Concluding remarks
The study presented in this paper shows that the design of FS 2500 TC ensures a correct train shunt performance including in the worst shunt operation scenario. Moreover, the TC has a vast reserve of train shunt sensitivity which allows this TC to be used in railways with a very wide range of operating conditions. The reserve in shunt sensitivity could also enable further optimisation of other TC operating parameters.

The investigation of FS 2500 TC confirms the TC performance as specified by the manufacturer. This gives confidence in the correctness of TC model used for the simulations. The results obtained demonstrate the usefulness of the specialised TC simulation tool. They also point out the necessity for this program to be extended with a facility enabling a direct determination of the worst operation scenario for a specified TC operating range.
FIG. 13 Tuning of TC receiving end in train detection operation

FIG. 14 Effect of rail track conductance and train shunt resistance on train detection performance

FIG. 15 Position of minimum train shunt sensitivity at TC receiving end

FIG. 16 Train detection in the ESJ area
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References