

# Advanced methods of design of complex track circuits

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**Abstract** – Problems with implementation of complex track circuit design methods are described in this paper. These complex track circuits are called branched TCs, because they consist of several branches, mostly equipped with receivers. The adjustment table design of these TCs is therefore more complicated, because the calculation of variants with various places and lengths of branches has to be done. To verify the quality of TC design, the test of safe and reliable function has to be carried out. Implementation of these functions in SW tool, called TC Designer, which is based on Matlab environment, is also described in this paper.

**Keywords**- track circuit; railway signalling and interlocking; railway safety

## I. INTRODUCTION

Track circuit (TC) is fundamental subsystem of railway signalling and interlocking systems, which serves to safe detection of movement of railway vehicles. A safe operation of railway traffic is ensured by usage of this information, in order to avoid accidents. This implies the crucial role of these detection means for railway safety. Basic, most frequently used, TC consists of the three parts, source and receiver of the signal together interconnected with track, see Fig. 1a. This is the simplest topology, called straight TC. More complex topologies, so-called branched TC (BTC) have several branches of track and hence several receivers (however variants and with branches without receiver also exist), typical examples can be seen on Fig. 1b, 1c. These topologies of TC are used on junctions of railway stations with points.

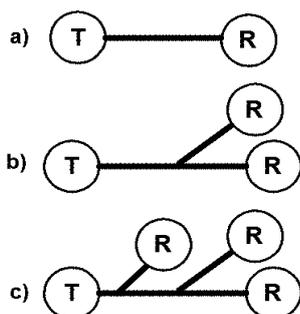


Figure 1. Examples of topology of track circuits.

The function of TC consists in supervision of the given track section, whether it is occupied by rail

vehicle (shunted state) or no (clear state). The signal is transmitted from the source to receiver in the clear state and the active signal is present on the receiver output. The rail track is short-circuited (so-called shunted) after entrance of vehicle to the section by its axles and signal transmission to the receiver is interrupted and its output is inactive. The shunt isn't perfect short circuit in real conditions however and therefore there is not zero voltage on the input of the receiver. Still, this voltage has to be low enough, not to activate the output of the receiver. In addition, the supervision the track sections of various lengths is required in practice and design of TC also has to be optimized for them. For this purpose, additional components (C, R) are present in the TC. The signal transmission can be optimised by setting of their values in particular TC. All receivers in branched TC have to be excited in clear state, whereas transition of at least one receiver to the inactive state is enough for detection of shunt. The ability of TC to detect specific failure - breaking of the rail is the third important analysis, which has to be carried out. More details about track circuit theory can be found in [1].

## II. MODEL OF THE TRACK CIRCUIT

Model of the track circuit is formed from cascade of two-port networks representing transmission of particular parts of TC, rail track  $A_T$  with length  $L$  and components of transmitter end equipment  $A_S$  and receiving end equipment  $A_R$  of TC, see Fig. 2.

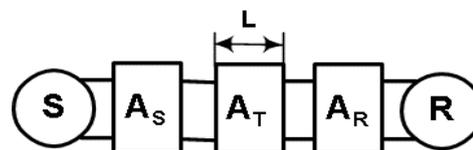


Figure 2. Model of straight track circuit.

These two-port networks are characterized by cascade matrices, whose elements have to be filled with values appropriate to the real features of TC. Example of equation system for this simplest case is stated in (1).

$$\begin{bmatrix} U_S \\ I_S \end{bmatrix} = A_S \times A_T \times A_R \times \begin{bmatrix} U_R \\ I_R \end{bmatrix} \quad (1)$$

The rail track can be considered as special kind of communication line and can be described by the same model,

$$A_T = \begin{bmatrix} \cosh(\gamma L) & Z_0 \sinh(\gamma L) \\ \sinh(\gamma L)/Z_0 & \cosh(\gamma L) \end{bmatrix}. \quad (2)$$

However, fundamental difference from the communication cables is in values of the primary parameters  $R$ ,  $L$ ,  $C$  and  $G$ , which are essentially different from obvious reasons, e.g. noncircular cross-section of rails etc. These values have to be obtained by measurement on the real rail track in the form of longitudinal impedance and transverse admittance.

The situation is significantly more complicated regarding BTC, see example on fig. 3, where the branch with length  $b$  is placed in distance  $x$  from the beginning of TC.

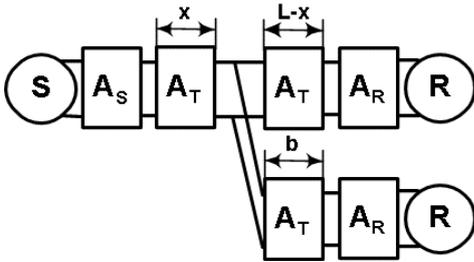


Figure 3. Model of branched track circuit.

The value of supply voltage and power consumption necessary for activation of the receiver in clear state is obtained by basic calculation at design of TC. Calculation is then performed on direction from receiver to source, as it is in compliance with equations (1) and (2). Consequently, the shunt, represented by resistance  $R_s$ , is inserted to the rail track and the voltage drop on receiver is calculated. The calculation has to be executed in cycle, where the place of shunt is moved with step of 5m over the rail track. Regarding BTCs, these conditions have to be fulfilled for all receivers simultaneously. Calculation is executed step by step that way the other branches of TC are replaced by corresponding input impedances and placed to the appropriate place of the rail track, see  $Z_{b\_in}$  on fig. 4, where  $p$  is place of the branch and  $x$  is current place of the shunt. At solving shunt state, the modelled shunt has also to be step by step inserted into all branches. The only rail track model is shown on this figure without equipment transmitting and receiving end of TC due to space shortage.

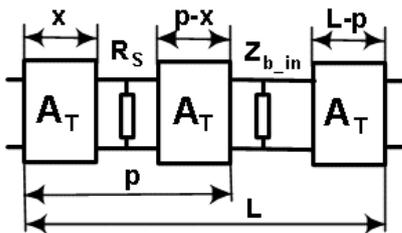


Figure 4. Example of rail track model of BCT with shunt in front of place of branch.

More details about modelling of TCs can be found in [2].

### III. OPTIMIZATION ANALYSIS

The computing result, at given parameter setting and configuration of the whole TC, has not to be naturally successful, i.e. the designed TC will not behave correctly. In this case, the correction of selected parameters of TC is necessary, first of all by means of adjustable component ( $C$ ,  $R$ ), how it was already aforementioned in introduction. The automation of optimal solution searching is realized by the help of optimization analysis, which is otherwise very elaborating task. The series of calculations is performed and according to entered criteria and adjusted limitations, the best feasible solution is selected. The GUI window of parameter setting of optimization analysis is shown on fig. 6.

### IV. TEST OF SAFETY

An analysis of behaviour of TC, under all considered faults of individual components of their equipment, is important function at design of TC. This is the fundamental requirement on all the railway signalling and interlocking systems that they have to behave safely also under all considered faults. Output track circuit have to change to the inactive state under all faults, which is the identical response as at occupation of TC by the vehicle. Superior logic of interlocking system has to evaluate this in a safe manner. Function executing this analysis is called test of safety. The series of calculations is executed with step-by-step change of individual component values, which simulate faults (e.g. short circuit, break-in of terminal etc.).

### V. SENSITIVITY ANALYSIS

A function of sensitivity analysis is, from aspects of the algorithm, to a certain degree similar to the test of safety, described in previous chapter. It is however the reliability type of analysis, which serves to verification that the receiver of TC will not randomly pass to inactive state and thus indicate false occupation of the track section. This behaviour would not be dangerous though, but it is unacceptable from operation point of view. The reliable preservation of receiver excitation is proved also at value changes of individual components and some of their combinations within selected tolerance limits.

### VI. PROPOSAL OF ADJUSTMENT TABLES OF TRACK CIRCUIT

A result of the whole process of track circuit proposal is the document, which is called Adjustment Tables (AT) of an appropriate type of TC. This document describes in detail all the parts creating the given TC, all its adjustable parameters and also the optimal set-up of the particular real built TC. This set-up is dependent on particular configuration of TC and its operational conditions. After approval of safety evaluator, this document is binding on set-up of TC for maintenance workers in operation.

All calculations are required to be carried out for required range of length of TC, as it was already premised in introductory part. The typical length range of the straight TC is up to the 1500m with the step of 50m. The typical length range of the branched

TC is for straight branch up to the 400m with the step of 25m. The AT proposal of BTC is significantly more complicated, because it is necessary to cover various variants of places and lengths of branches, which may occur in practice. The basic limitation is that the length of branch is at least 25m and next it cannot outmatch the length of straight branch. Algorithm of AT calculation is for simplification designed that way, in order to cover extreme cases, which are: shortest and longest branch placed at the beginning, in the middle and at the end of TC. The meaningful combinations are under consideration for BTCs with more branches. The result of calculations is the table, which determines the set-up of TC for given configuration and makes it possible to verify the correct set up of TC in practice by operational measurement. An example of such table, which is the kernel of the AT document, is in table 1. For particular lengths of straight branch of TC there are stated values of adjustable components, here C1 plus C6, next the necessary supply voltage Unom, power requirement of TC, marked N, and the range of voltage and phase (indices max, min) on receiver of straight branch (index 1) plus on receivers, in this case, of the two branches (indices 2 and 3) in the clear, shunt (index s) and broken rail (index h) states.

#### VII. IMPLEMENTATION IN TC DESIGNER SW TOOL

TC Designer is SW tool serving to design track circuits and the creation of the adjustment tables. The tool is created as graphic shell of the computation environment Matlab and derives benefit from his powerful engine and advanced math functions. How it was already introduced in chap. X, the design of TC is based on matrix calculations, in addition with complex numbers. These operations have just the strong support in Matlab. The graphic shell was created, in order to the user didn't have to know the commands and functions of Matlab, their syntax, parameters and rules of writing scripts. More details about creating GUIs in Matlab environment can be found in [3].

The main GUI window, in which the parameters of designed TC are set, is shown on figure X. The general model of TC, which covers all practically used possibilities of TC configuration, is displayed at the bottom of window. The button bar on the right of the window makes it possible to carry out particular

analyses, mentioned in chapters III, IV and V separately for the particular set configuration of TC (including topology). The button Adjust. Tables then makes it possible the automated proposal of the adjustment table, when the optimization analysis is executed in cycle for particular TC lengths (including variants of branches for BTC). The test of safety and sensitivity analysis is then performed for selected optimal solution for particular lengths. The result of calculation is adjustment table for given type of TC, including full verification of his safe and reliable function. Quantity of computed variants at real TC proposal is in order of tens of thousands as far as hundreds of thousands according to the type of TC and entered parameters of the proposal.

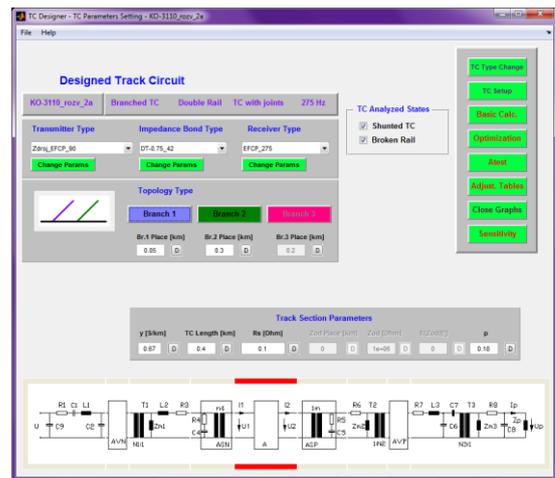


Figure 5. Main window of TC Designer.

The results of basic and optimization analyses can be displayed in result windows, which are shown on Fig. 7 and 8. As can be seen there, a number of other parameters is calculated in order to enable detailed analysis of TC behaviour by the user.

The dependency graphs are at user's disposal for optimization analysis, which make possible to investigate trends, example is shown Fig. 9. The results of complex analyses are saved, with regard to their largeness, to the text file. The adjustment table itself is saved in format of Excel program.

TABLE I. ADJUSTMENT TABLE OF BTC WITH TWO BRANCHES

L	C1, C6	Unom	N	Ud1 min	Ud1 max	Alfa1 min	Alfa1 max	Ud1s	Ud1h	Ud2,3 min	Ud2,3 max	Alfa2,3 min	Alfa2,3 max	Ud2,3s	Ud2,3h	Ir
[m]	[uF]	[V]	[VA]	[V]	[V]	[°]	[°]	[V]	[V]	[V]	[V]	[°]	[°]	[V]	[V]	[A]
25	3.4, 1.2	28,43	6,3	16,4	19	30	30	10,8	1,2	17,7	25,6	18,1	25,9	12,7	1,3	0,13
50	3.2, 1.1	31,18	8,2	16,3	20	30	30	10,7	1,3	17,7	29,1	15,7	26	13,5	1,5	0,25
75	3.1, 1.1	34,66	10,5	16,4	22	32	33	10,7	1,5	18	33,4	15,1	29,6	15,2	1,7	0,39
100	3, 0,9	43,94	19,4	16,3	26	28	47	12,9	1,8	17,6	47,7	9,9	44,8	20,6	2,1	0,29
125	2.7, 1.1	52,29	27,1	16,7	30	30	53	14,8	2,5	18,1	56,6	9,2	49,7	23	2,9	0,4
150	2.6, 1	59,96	36,4	16,4	32	26	53	15,6	2,9	17,7	64,8	4,9	50,4	26,2	3,4	0,53
175	2.5, 1	68,73	48,1	16,5	35	26	55	16	3,4	17,8	73,9	3,1	52,2	29,4	4	0,56
200	2.4, 1	76,43	59,8	16,2	37	25	55	15,9	3,9	17,5	80,9	0,9	52,4	31,9	4,7	0,57

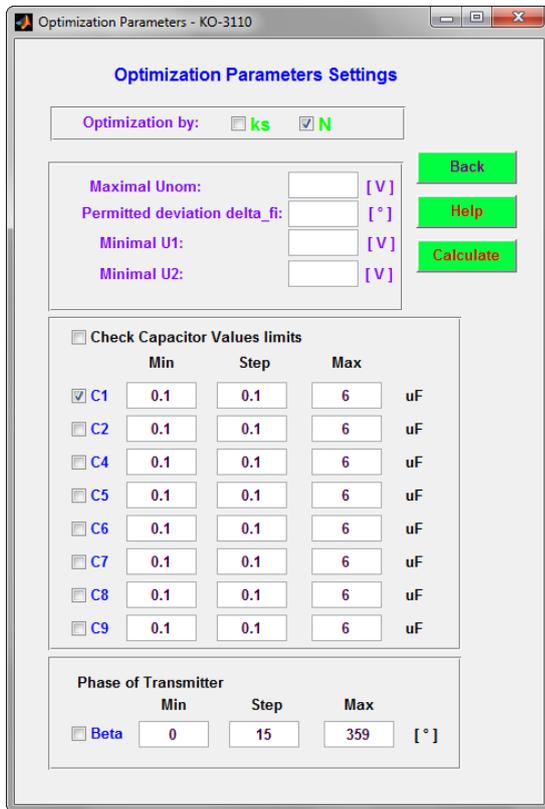


Figure 6. Window of optimization analysis parameters setting.



Figure 7. Window with display of results.

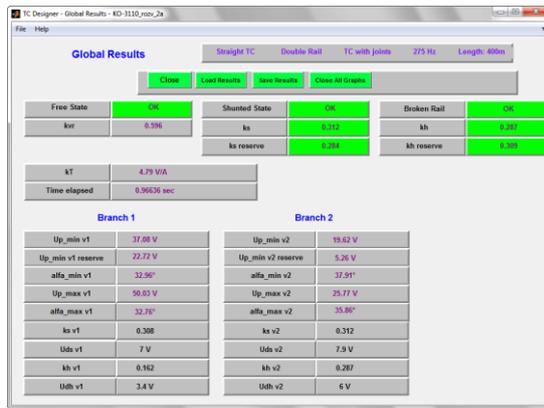


Figure 8. Window with display of results.

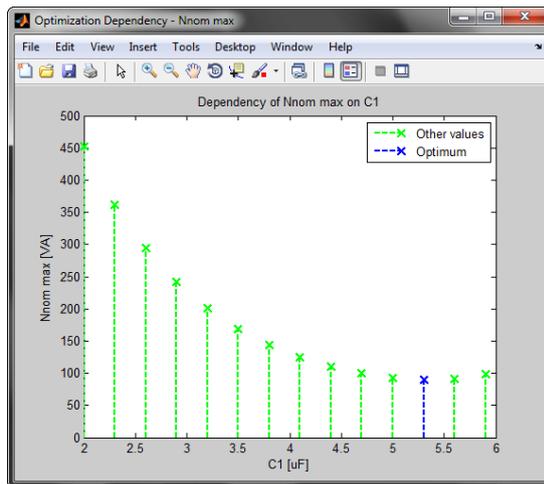


Figure 9. Window of dependency graph - power requirement of TC on C1 values.

## VIII. SUMMARY

The problems of track circuit design with emphasis on diversity for design of complex branched TC is briefly described in this article. The advanced methods verifying safety and quality of the design are also described. Next, the paper deals with the description of TC Designer program, which was developed for the support of TC design and the methods described above are implemented in this program.

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