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Investigation of Branchy Track Circuit Parameters

V. Gargasas, A. Knyš

Department of Control Technology, Kaunas University of Technology,
Studentų str. 48-220, LT-51367 Kaunas, Lithuania, e-mail: vytautas.gargasas@ktu.lt

Introduction

Track circuit is the main part of automation circuitry that is used to safeguard railroad traffic safety. The main function of a track circuit is to control the occupation of a railroad section. Lots of various types of track circuits are in use. Lithuanian railway system starting from beginning of electrical signalling until present day mostly uses track circuits of 50 Hz current signalling. Only at electrified sections frequency of signalling current is set to 25 Hz to safeguard receiver of track circuit from impact of 50 Hz power current [1, 2]. There are also track circuits that implement constant current to feed the track receiver and to control railroad section. Actually that is all the variety of track circuits implemented at Lithuanian railway system [8].

During the design of a track circuit the most important task is to find a correct set of track circuit feeder electric parameters:

- The feeder current must be high enough to ensure the relay-on state when controlled section is free (normal mode);
- In case the train is in controlled section (shunt mode) the feeder current must be low enough to ensure the relay-off state – the section is occupied state.

At this point to calculate optimal feeder voltage all the factors that can be significant (i.e. rail resistance, track circuit length, conductance of road ballast, frequency of signalling current etc.) have to be investigated.

Usually, when there are only a few track circuit types in use, the track circuit design rules and appropriate tables are prepared. They give information on different scheme electrical parameters and other necessary information that is important during the design of particular track circuit. This information saves designing time as no additional calculations have to be made. All the necessary information about electrical parameters is given in these tables partitioned by type of track circuit, length or count of branches in a section, length of separate sections, etc [4, 5, 9].

During the modernisation of Šiauliai – Klaipėda railway sector new type of electronic track circuits were implemented. Those are type TRC3 audio frequency track circuits that utilise signalling current in one of the following frequencies: 420, 480, 580, 720 or 780 Hz. Additionally the signalling current of specific frequency is manipulated at 8 or 12 Hz frequency.

There is almost no literature on audio frequency track circuits or the processes that occur in track line at audio frequency. Also there are no tables prepared that may be helpful during the designing of these track circuits.

The novelty of the work lies in application of theoretical methods to analyse branchy track circuits type TRC3. The aim of the work is to investigate parameters of a branchy track circuit type TRC3 at normal operating conditions.

Track line is the only part of track circuit that has variable parameters. The parameters of track line describe or sets track circuit operating conditions. The main task of track line analysis is the calculation of track circuit feeder voltage. The first part of analysis is calculation of track line parameters at audio frequency. The second part is the investigation of impact of track line branches count and the length of separate sections on track circuit operating conditions.

Mathematical model of a branchy track line

Track line parameters of a track circuit can be calculated using simple theoretical electrotechnics formulas. However classic theory is limited to a simple task when the line analysed has no branches. Then track line is modelled using a quadripole model that has voltage and current inputs and outputs and their relation is described using quadripole coefficients.

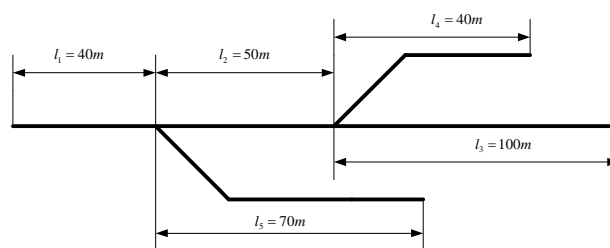The schematics of a branchy track line analysed is presented in Fig. 1.

Fig. 1. Scheme of a branchy track line analysed

To calculate parameters of a branchy track line presented in Fig. 1 we suggest forming a structure of quadripoles where each of the quadripoles represents section of track line between the shunt and line-end or between two shunts. The most complicated structure of a branchy track circuit is a three-branch structure. Modelling of such a structure leads to a five quadripoles combination, presented in Fig. 2.
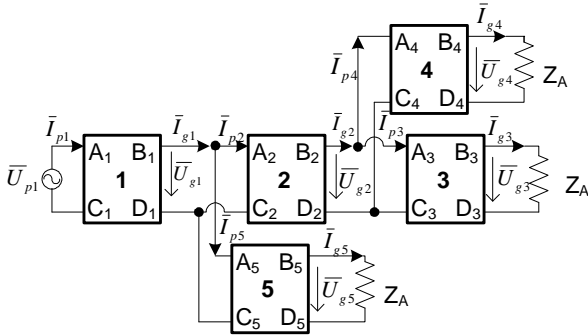

Fig. 2. Layout of quadripole combination of a branchy track line

Let us suppose that n is a quadripole sequence number. Then I_{pn} and U_{pn} is current and voltage of quadripole input respectively. $\bar{I}_{gn}$ and $\bar{U}_{gn}$ is quadripole output current and voltage respectively. $\bar{U}_{p1}$ and $\bar{I}_{p1}$ is voltage and current that is supplied to the track circuit by the feeder. Additional condition – branch marked by quadripole number 3 is the branch that has most distant relay-end from the feeder, even more distant than branches marked by quadripoles 4 and 5:

$$\begin{cases} l_2 + l_3 > l_5, \\ l_3 > l_4; \end{cases} \quad (1)$$

here l_n – length of non-branchy sections of track line.

The load of the quadripoles Z_A is the resistance of relay-ended equipment. It is considered, that resistance of the load is linear and equal for each of the branches. The Fig. 2 layout is suitable to analyse normal mode or shunt mode of the track circuit. However as the mode changes, the coefficients of the quadripoles (line parameters) also change.

The aim of the task is to evaluate parameters of the track line when in normal mode and to calculate the lowest voltage $\bar{U}_{p1}$ so that each of the road receivers at each of the branches is on. The second task is to investigate changes in voltages $\bar{U}_{g4}$ and $\bar{U}_{g5}$, or how high they are relative to $\bar{U}_{g3}$.

In order to evaluate load Z_A, the lowest voltage $\bar{U}_{g3}$ and corresponding current $\bar{I}_{g3}$ is measured. Then using quadripole coefficients, load Z_A and voltage $\bar{U}_{g3}$, the feeder voltage $\bar{U}_{p1}$ and current $\bar{I}_{p1}$ can be described [3]:

$$\begin{cases} Z_A = \dfrac{\bar{U}_{g3}}{\bar{I}_{g3}}, \\[2mm] \bar{U}_{g2} = A_3 \bar{U}_{g3} + B_3 \bar{I}_{g3}, \quad \bar{I}_{p3} = C_3 \bar{U}_{g3} + D_2 \bar{I}_{g3}, \\[2mm] \bar{U}_{g4} = \dfrac{\bar{U}_{g2}}{A_4 + B_4/Z_A}, \quad \bar{I}_{p4} = \bar{U}_{g4}(C_4 + D_4/Z_A), \\[2mm] \bar{I}_{g2} = \bar{I}_{p4} + \bar{I}_{p3}, \quad \bar{I}_{p2} = C_2 \bar{U}_{g2} + D_2 \bar{I}_{g2}, \\[2mm] \bar{U}_{g1} = A_2 \bar{U}_{g2} + B_2 \bar{I}_{g2}, \quad \bar{U}_{g5} = \dfrac{\bar{U}_{g1}}{A_5 + B_5/Z_A}, \\[2mm] \bar{I}_{p5} = \bar{U}_{g5}(C_5 + D_5/Z_A), \quad \bar{I}_{g1} = \bar{I}_{p2} + \bar{I}_{p5}, \\[2mm] \bar{U}_{p1} = A_1 \bar{U}_{g1} + B_1 \bar{I}_{g1}, \quad \bar{I}_{p1} = C_1 \bar{U}_{g1} + D_1 \bar{I}_{g1}. \end{cases} \quad (2)$$

Quadripole coefficients in normal mode are calculated as described in classical theoretical electrotechnics:

$$\begin{aligned} A_n &= \cosh(\gamma \cdot l_n), \quad B_n = Z_b \sinh(\gamma \cdot l_n), \\ C_n &= \frac{\sinh(\gamma \cdot l_n)}{Z_b}, \quad D_n = A_n. \end{aligned} \quad (3)$$

The coefficient of propagation γ and undulatory resistance Z_b is estimated at the length of track line according to track line isolation resistance r_i, resistivity of track line Z that is complex and is current frequency dependant. Z can be found at special tables, that presents experimental data for each type of rail.

Mathematical experiment

Investigation object is a three-branch track line that has separate sectors of given length: $l_1=40$ m, $l_2=50$ m, $l_3=100$ m, $l_4=40$ m, $l_5=70$ m. The results are presented in Table 1.

Table 1. Parameters of a branchy track line using audio frequency track circuit

f_{sig}, Hz	$|U_{p1}|$, mV	$|U_{g4}|$, mV	$|U_{g5}|$, mV	n_4	n_5
420	140	42.5	60.4	1.42	2.01
480	156	43.9	63.5	1.47	2.12
580	184	46.3	68.2	1.54	2.27
720	229	49.5	74.5	1.65	2.48
780	248	50.7	77.0	1.69	2.57

The results are very important during the setup of track circuit and checking its operation. Parameters n_4 and n_5 show how many times voltage at the beginning of the sector is higher related to the most distant end of the sector. These parameters are reference in designing of relay-end equipment – the smoothing transformers to equalise voltages at all road receivers at he same track circuit are selected according to it. Technically the coefficient of transformation is limited to n = 4.16 and this limits possible lengths of a branchy track line and also some other parameters.

The resistance of track line isolation r_i also has influence on calculation results. In real life it changes: if

there is higher humidity on rail ballast, the electrolytic conductance occurs and isolation resistance decreases. At the temperatures below 0°C electrolytic conductance is the lowest and thus r_i is the highest. The branchy track circuits control sectors where train passes shunts. Shunts make train trajectory curvy and this causes that shunts are mostly contaminated by powdery products that crumbled out of the freight train. This causes all the conditions for electrolytic conductance to occur and decreases the isolation resistance [6, 7].

In order to investigate what influence track line isolation has on track circuit efficiency, the dependency of sector five and three relay-end voltage ratio on isolation resistance r_i was analysed at all the frequencies that are implemented (Fig. 3).
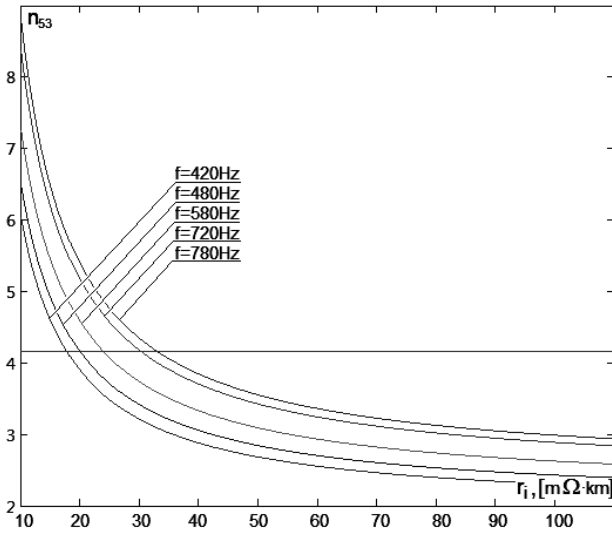

Fig. 3. Dependency of n_{53} on isolation resistance r_i [Ω*km]

Fig. 3 shows that at certain value of r_i relay-end voltage ratio is too high (n_{53}>4.16) to compensate it with smoothing transformer and the track circuit can not be tuned. At frequency of signaling current of f_{sig} = 780 Hz the scheme can be tuned only when r_i>0.0332 Ω*km. At normal conditions r_i is never below 0.5 Ω*km, so it can be stated that audio frequency track circuit is resistant enough to r_i changes and that track line resistance r_i is not the main factor during investigation of audio frequency track circuit in normal mode.
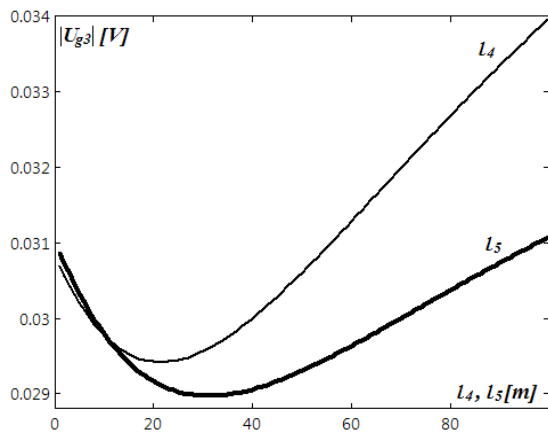

Fig. 4. Dependency of $\left|U_{g3}\right|$ on sector length l_4 and l_5

It is clear that change in length of one of the track line sectors results in change of voltage at relay-end of track line. In order to evaluate impact of track sector length on voltage of most distant relay-end, the mathematical experiment was performed. The feeder voltage and sector lengths l_1, l_2 and l_3 were set constant. As the sector 5 length l_5 changes the voltage at relay-end $\left|U_{g3}\right|$ was recalculated. The same was repeated with sector 4 and the results are presented in Fig. 4.

Experimental data can be approximated using the following polynomial (4):

$$\begin{cases} \left|U_{g3}\right| = 3.6\cdot10^{-16}\cdot l_4^6 - 4.1\cdot10^{-13}\cdot l_4^5 + 1.7\cdot10^{-10}\cdot l_4^4 - \\ -3.7\cdot10^{-8}\cdot l_4^3 + 3.9\cdot10^{-6}\cdot l_4^2 - 1.2\cdot10^{-4}\cdot l_4 + 0.031, \\ \\ \left|U_{g3}\right| = 3.3\cdot10^{-16}\cdot l_5^6 - 3.5\cdot10^{-13}\cdot l_5^5 + 1.5\cdot10^{-10}\cdot l_5^4 - \\ -3.1\cdot10^{-8}\cdot l_5^3 + 3.4\cdot10^{-6}\cdot l_5^2 - 1.4\cdot10^{-4}\cdot l_5 + 0.031, \end{cases} \quad (4)$$

where $l_4 = 0...100, l_5 = 0...100$.

The results presented in Fig. 4 show what influence the sectors 4 and 5 length have on most distant relay-end voltage. The road receiver reacts more sensitively to a change of sector 5 length rather than sector 4 length. Also the presence of potentially dangerous length of sectors was discovered (l_4=23m and l_5=31m).

The voltage $\left|U_{g3}\right|$ at relay-end of track line is stepped-up by transformer n=38 times. In this case $\Delta\left|U_{g3}\right|$=0.001 V gives 0.038 V deviation, which, in turn, equals 9.5% of relay operation voltage, that is 0.4 V. It appears that such a small change is significant for correct functioning of the circuit.

One more factor that may limit possibilities of scheme tuning is the ratio of voltages at sector endings (Fig. 5).
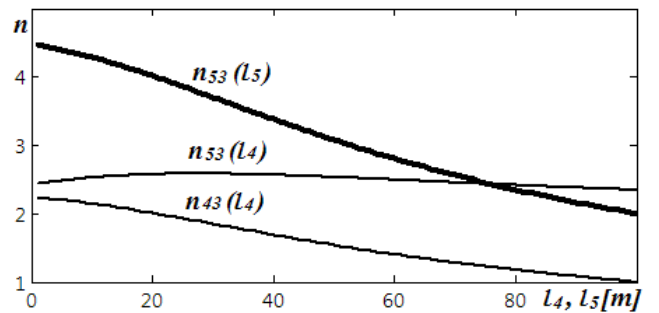

Fig. 5. Dependency of voltages ratio n at sector endings on sector length (l_4 and l_5)

Fig. 5 shows that at sector 5 length l_5<15 m ratio n_{53} is more than 4.16 and in this case tuning of track circuit is not possible. Change in sector 4 length voltage ratios n_{53} or n_{43} do not achieve specified ratio at which tuning of track circuit is no longer possible. Critical parameters or critical track lengths can be specified in each particular case using the suggested analysis.

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Conclusions

The analysis and results of presented system of equations dedicated to calculate parameters of track line with three branches allows concluding in following:
1. The results show that change in length of a branch nearer to the feeder results in higher influence on track circuit operation in normal mode. A critical length of a branch, nearest to the feeder, exists at which tuning of the track circuit becomes impossible (dependency on a branchiness).
2. The critical lengths of branches exist. In this case the most adverse conditions for normal mode occur.
3. The results show that in normal operating conditions, when r_i is never below 0.5 Ω*km, there will never be such a condition when tuning of the circuit is impossible (dependency on isolation resistance).

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V. Gargasas, A. Knyš. Investigation of Branchy Track Circuit Parameters // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009.– No. 7(95).– P. 21–24.

Audio frequency track circuit is a new generation electronic schematics to control occupation of a rail sector. The signalling currents used in these circuits are at 12 or 8 Hz manipulated 420, 480, 580, 720 or 780 Hz frequency currents. It is a higher frequency of current related to ordinary track circuits, so before calculation the influence of current frequency on track line parameters must be investigated. A new model of branchy track line parameter calculation model was suggested, the results of the mathematical experiment were presented. It was shown that there are critical lengths of separate branches that make inauspicious circumstances for normal mode functionality. Results show that there are certain circumstances at which track circuit can not be tuned correctly. Ill. 5, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

В. Гаргасас, А. Кныш. Анализ параметров разветвленной рельсовой линии тоновой частоты // Электроника и электротехника.– Каунас: Технология, 2009. – № 7(95). – С. 21–24.

Рельсовая цепь тональной частоты – это электронная схема нового поколения для контроля занятости рельсового участка. В ней исспользуются сигнальные токи 420, 480, 580, 720 и 780 Герц, манипулированные частотами 12 или 8 Герц. Это токи большей частоты по сравнению с токами в обыкновенных цепях, поэтому обязательно нужны расчеты, какое влияние на параметры рельсовой линии оказывает частота. Представлен математический метод расчета параметров разветвленной рельсовой линии, прокоментированы результаты математического эксперимента. Показано, что существуют критические длины ветвей, при которых проявляются неблагоприятные условия для фукционирования схемы в нормальном режиме. Результаты показывают, что существуют некоторые условия, при которых невозможно наладить работоспособность схемы рельсовой цепи. Ил. 5, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Gargasas, A. Knyš. Šakotosios toninio dažnio bėgių linijos parametrų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 7(95). – P. 21–24.

Toninio dažnio bėgių grandinė – tai naujos kartos elektroninė bėgių ruožo užimtumo schema. Joje naudojama 12 arba 8 Hz manipuliuota 420, 480, 580, 720 arba 780 Hz dažnio signalinė srovė. Tai aukštesnio dažnio srovė nei įprastose bėgių grandinių schemose, todėl atliekant skaičiavimus būtina atsižvelgti į dažnio įtaką bėgių linijos parametrams. Pasiūlytas matematinis šakotosios bėgių grandinės linijos parametrų skaičiavimo modelis, pakomentuoti atliktų matematinių eksperimentų rezultatai. Parodyta, kad esti kritiniai atšakų ilgio taškai, kuriuose susidaro nepalankios sąlygos schemai funkcionuoti normaliu režimu. Rezultatai rodo, kad esant tam tikroms sąlygoms neįmanoma suderinti bėgių grandinės schemos veikimo. Il. 5, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).