Research on insulation joint damage of the station track circuit in high speed and heavy load condition

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Abstract. In high-speed and heavy-load operation environment, the insulation joints of the station track circuit are damaged in many stations, which caused the carrier information of the adjacent sections to interfere with each other, endangered the safety of the train and reduced the reliability of the track circuit. In order to solve the incorrect code problem caused by the insulation joint breakage, we analysed the insulation damage situation for the station track circuit and the structural principle of BES choke transformer. Then the different structures of the insulation damage protection circuit are given and the relevant parameters are obtained, and verifying the anti-interference ability of the new BES choke transformer. Finally, a complete four-terminal network model of the new BES choke transformer is established. And its four-terminal network parameters are calculated by matlab simulation, which provides the theoretical basis for establishing the track circuit complete system.

1 Introduction

The ZPW-2000 track circuit is an important component of the train control system, which has the ability to transmit train information, train positioning and other main functions[1]. The section line adopts ZPW-2000 series non-insulated track circuits, due to the railways continuous development towards high speed and heavy load, in order to ensure the continuity of train control information, the section and station are adopt the same standard track circuit in high speed and heavy load situation, that is, the ZPW-2000 integrated track circuit[2]. When the ZPW-2000 track circuit is applied to the station, the non-insulated track circuit is not suitable. The insulated track circuit must be adopted, using the mechanical insulation joint to divide the adjacent track circuit section. The choke transformer is used to conduct the traction current and ensure the reliable transmission of frequency-shift signal in the mechanical insulation joint. The insulated track circuit in station is shown in Figure 1.

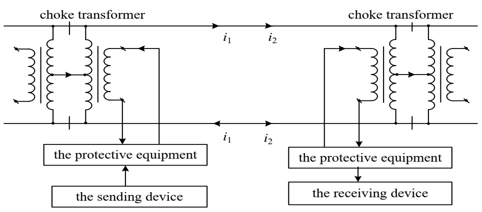

Figure 1. Structure of the insulated track circuit in station

As one of the key equipment of the station track circuit, the insulation joint plays an important role in the auxiliary positioning of the train and the isolation of the adjacent section frequency shift signals[3]. It is easy to produce arcing phenomenon when the wheel set of high-speed train passes through[4], which leads to serious burning loss of insulating joint and rail.

In China high-speed operation lines, such as Beijing-Shanghai high-speed railway and so on, have suffered burnout of mechanical insulation joints and occurred more than 300 times, which seriously affecting the normal operation of high-speed railway[5]. In view of the burning damage of mechanical insulation joint in high-speed railway passenger stations, the domestic scholars mainly focuses on that how to alleviate the burning damage of mechanical insulation joint[6], and did not give specific solutions to the problem of the carrier frequency mutual interference of the adjacent track circuit section in station. Based on the improvement of the traditional choke transformer, this paper proposes a kind of rail-side protection scheme that can effectively prevent the carrier frequency mutual interference of the adjacent track circuit section caused by the mechanical insulation damage in station.

2. Analysis of insulation joint damage

When the station track circuit use the insulation section to divide the adjacent track section, if the insulation section has unilateral or bilateral insulation damage and iron filings, the signal of the adjacent

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section will be transmitted across the zone, causing the vehicle equipment receive the mistake code, thus endangering the train safety[7]. The flow direction of the adjacent section signal current in current track circuit is shown in Figure 2.

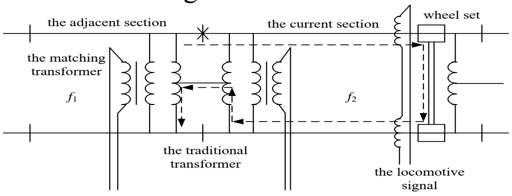

Figure 2. Signal current cross-region transmission diagram

We take a third-line station as an example. The two sides of the station are the main lines, and the middle is the third line with running in two directions. According to the carrier frequency configuration principle, we can know that no matter how it is arranged, the carrier frequency of the third line will be the same as one of the main lines. According to one of the situations, the station carrier frequency configuration is shown in Figure 3.

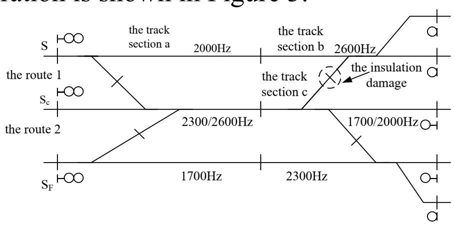

Figure 3. The third-line station structure

Now the two trains are running in the uplink direction of the route 1 and 2 respectively. When the train runs in the track section a, the insulation joint between the section b and c is damaged for some reason, so the carrier frequency information of section c will be transmitted to section b. When the train runs to section b, the on-board equipment will use 2000Hz carrier frequency information of section c as effective information and ignore 2600Hz carrier frequency information of section b, which threatens the train safety. In the long-term application of the signal system, we must find reasonable solution to ensure the railway operation is an inevitable requirement.

3. Structure of BES choke transformer

The track circuit of the high-speed and heavy-load stations in China adopts the insulated track circuit system, and a choke transformer is used at the mechanical insulation joint to conduct the traction current of the adjacent track section. In order to adapt to the new transportation requirements and meet the new anti-interference requirements of the signal system, at present, The BES choke transformer is generally used in high-speed and heavy-duty railway stations in China. The structure of BES choke transformer is shown in Figure 4.

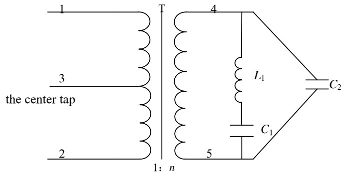

Figure 4. Structure of BES choke transformer

The 50Hz series resonant circuit composed of L_1C_1 in the adapter part is used to reduce interference energy. The lifting capacitor C_2, the 50Hz series resonant circuit and the equivalent inductance of the choke transformer secondary side coil together form a parallel resonance of the frequency-shifted signal, showing high impedance and the frequency-shifted signal impedance value converted to the primary side of the choke transformer is more than 17Ω, which can meet the anti-interference requirements and ensure the reliable transmission of frequency-shifted signal. Where $n = 30$, $C_1 = 30\mu F$, $L_1 = 0.338H$[8], the value of C_2 is related to the track section carrier frequency, the C_2 values corresponding to 1700Hz, 2000Hz, 2300Hz, and 2600Hz are 31.10nF , 22.47nF, 16.98nF, 13.29nF.

4. Structure of insulation damage protection circuit

The choke transformer is one of the important equipment of the station track circuit, we proposed to parallel the insulation damage protection circuit on the BES choke transformer secondary side to solve the adjacent section carrier frequency mutual interference.

When the track circuit insulation joint of the high-speed and heavy-load stations is damaged, the series resonance circuit of the insulation damage protection circuit can be used to eliminate the adjacent section carrier frequency interference information. Under normal circumstances, the parallel resonance circuit is used to ensure the signal reliable transmission of the current section. And for on-board equipment, the track circuit always has high reliability and high safety, ensuring the reliable transmission of frequency-shifted signal. Due to the different configuration of the up and down track circuit carrier frequency, the insulation damage protection circuit has different structures for different lines.

4.1 Insulation damage protection circuit with carrier frequency 1700/2000Hz

When the insulation joint is damaged for some reason, the 2300/2600Hz carrier frequency information of the adjacent section will be transmitted to the current section, which can cause interference to 1700/2000Hz carrier frequency information of the current section. According to the principle of series-parallel resonant circuit, the insulation damage protection circuit structure for 1700/2000Hz is shown in figure 5.

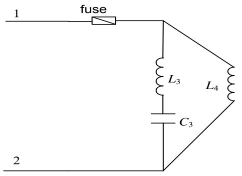

Figure 5. The protection circuit of 1700/2000Hz

When the current section frequency is 1700Hz, L_3C_3 forms series resonance of 2300Hz, which is used to eliminate 2300Hz interference frequency. Since L_3C_3 constitutes series resonance of 2300Hz, it is capacitive to the 1700Hz frequency, so through the parallel L_4, it is combined with L_3C_3 series resonance circuit to form parallel resonance of 1700Hz, which can ensure that the normal transmission of the current section signal. When the current section frequency is 2000Hz, the circuit principle is the same as 1700Hz.

According to the above analysis, the following formula can be obtained:

$$\omega_1^{\,2} L_3 C_3 = 1 \qquad (1)$$

$$\frac{1}{\omega_2 C_3} - \omega_2 L_3 = \omega_2 L_4 \qquad (2)$$

$$L_3 = \frac{L_4}{(\frac{f_1}{f_2})^2 - 1} \qquad (3)$$

Take C_3 = 85nF, when the current section frequency is 1700Hz, according to formula (1) and (3), L_3 = 56.39mH, L_4 = 45.11mH. When the current section frequency is 2000Hz, according to the formula, L_3 = 44.13mH, L_4 = 44.30mH.

4.2 Insulation damage protection circuit with carrier frequency 2300/2600Hz

When the insulation joint is damaged for some reason, the 1700/2000Hz frequency information will be transmitted to the current section, which can cause interference to 2300/2600Hz frequency information. According to the principle of series-parallel resonant circuit, the insulation damage protection circuit structure 2300/2600Hz is shown in figure 6.

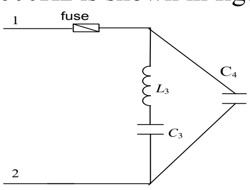

Figure 6. The protection circuit of 2300/2600 Hz

When the current section frequency is 2300Hz, L_3C_3 forms series resonance of 1700Hz, which is used to eliminate the 1700Hz interference frequency. Since L_3C_3 constitutes series resonance of 1700Hz, it is capacitive to the 2300Hz frequency, so through the parallel capacitance C_4, it is combined with L_3C_3 series resonance circuit to form parallel resonance of 2300Hz, which can ensure the current section signal normal transmission. When the current section carrier frequency is 2600Hz, the circuit principle is the same as 2300Hz. And the following formula can be obtained:

$$\omega_2 L_3 - \frac{1}{\omega_2 C_3} = \frac{1}{\omega_2 C_4} \qquad (4)$$

$$C_4 = \frac{C_3}{(\frac{f_2}{f_1})^2 - 1} \qquad (5)$$

when the current section frequency is 2000Hz, according to formula (1) and (5), L_3=96.30mH，C_4=106.25nF. When the current section carrier frequency is 2600Hz, L_3=74.60mH，C_4=123.20nF.

4.3 Anti-interference ability analysis of new BES choke transformer

According to the relevant standards of choke transformer equipment, the input impedance of new BES choke transformer to the frequency-shifted signal is more than 17Ω.

According to the parallel resonant principle:

$$X_{s2} = \frac{Q}{\omega C} = Q\omega L \qquad (6)$$

According to the BES type choke transformer structure, we can obtain equation (7), (8) and (9).

$$X_{s21} = \frac{Q_1 Q_2 L_4 \omega}{Q_1 + Q_2 \omega^2 L_4 C_2} \qquad (7)$$

$$X_{s22} = \frac{Q_1 Q_2}{Q_1 \omega C_4 + Q_2 \omega C_2} \qquad (8)$$

$$X_s = \frac{X_{s2}}{(n/1)^2} \qquad (9)$$

According to the simulation study, Q_1=25，Q_2=50，$\omega=2\pi f$. According to the above formula, the input impedance of new BES type choke transformer for different frequency shift signals are shown in Table 1.

Table 1. The impedance value of different carry frequency

the carry frequency (Hz)	1700	2000	2300	2600
the signal impedance value (Ω)	20.27	19.67	27.47	22.73

And the input impedance of new BES choke transformer are greater than 17Ω, which can meet the requirements of anti-interference.

5. Establishment of four-terminal network model

According to rail characteristics, the track circuit is equivalent to the transmission line with uniformly distributed parameters. The signal transmission characteristics can be described by four-terminal network[9]. Through comparative analysis, the BES choke transformers complete model mainly consists of ideal autotransformer, equivalent excitation impedance, ideal transformer, adapter part, etc[10]. And each part is equivalent to the corresponding four-terminal network, as shown in Figure 7, the transmission equation can be expressed as:

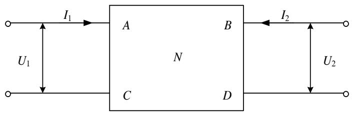

Figure 7. The four-terminal network model

$$\begin{bmatrix}U_1\\I_1\end{bmatrix}=\begin{bmatrix}A&B\\C&D\end{bmatrix}\begin{bmatrix}U_2\\I_2\end{bmatrix}=N\cdot\begin{bmatrix}U_2\\I_2\end{bmatrix} \quad (10)$$

According to the above analysis, the four-terminal network model of new BES choke transformer with 1700/2000Hz and 2300/2600Hz are $N_{ZPW\text{-}X}$ and $N_{ZPW\text{-}S}$ respectively.

$$N_{ZPW\text{-}X}=\begin{pmatrix}1&0\\ \frac{1}{R_M}+\frac{1}{j\omega L_M}&1\end{pmatrix}\begin{pmatrix}\frac{1}{n}&0\\ 0&n\end{pmatrix}\begin{pmatrix}1&0\\ \frac{1}{j\omega L_2}&1\end{pmatrix}\begin{pmatrix}1&0\\ j\omega C_2+\frac{1}{r+j\omega L_1+\frac{1}{j\omega C_1}}&1\end{pmatrix}\begin{pmatrix}1&0\\ \frac{1}{j\omega L_4}+\frac{1}{j\omega L_3+\frac{1}{j\omega C_3}}&1\end{pmatrix} \quad (11)$$

$$N_{ZPW\text{-}S}=\begin{pmatrix}1&0\\ \frac{1}{R_M}+\frac{1}{j\omega L_M}&1\end{pmatrix}\begin{pmatrix}\frac{1}{n}&0\\ 0&n\end{pmatrix}\begin{pmatrix}1&0\\ \frac{1}{j\omega L_2}&1\end{pmatrix}\begin{pmatrix}1&0\\ j\omega C_2+\frac{1}{r+j\omega L_1+\frac{1}{j\omega C_1}}&1\end{pmatrix}\begin{pmatrix}1&0\\ j\omega C_4+\frac{1}{j\omega L_3+\frac{1}{j\omega C_3}}&1\end{pmatrix} \quad (12)$$

According to the four-terminal network model analysis of the new BES choke transformer, the matlab is used to simulate calculation N_{ZPW}. The four-terminal network parameters of new BES choke transformer are shown in Table 2.

Table 2. The four-terminal network parameters of choke transformer with insulation damage protection circuit

C_2(nF)	L_4(mH)	C_4(nF)	carry frequency (Hz)	*A*	*B*	*C*	*D*
31.10	45.11	/	1700	1/30	0	0.00070-0.0038*i*	30
22.47	35.30	/	2000	1/30	0	0.00060-0.0142*i*	30
16.98	/	106.25	2300	1/30	0	0.00060-0.0071*i*	30
13.29	/	123.20	2600	1/30	0	0.00060-0.0009*i*	30

6. Conclusion

Aiming at the problems of the adjacent section track circuit carrier frequency mutual interference caused by the insulation joint damage in station track circuit, this paper put forward the relative rail-side protection scheme. By using the relevant anti-interference indexes, it is verified that new BES choke transformer can meet the anti-interference requirements. Finally, the four-terminal network model of BES choke transformer is established, and the relevant four-terminal network parameters are obtained, which provides important theoretical basis for the establishment of the complete track circuit system model.

Acknowledgement

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