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Analysis of Temperature Impact on Audio Frequency Track Circuits using Linear Regression Model

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Abstract. Track circuits form a critical part of the railway infrastructure, indicating when sections of track are clear or occupied. One of the drawbacks of track circuits is that their performance is related to weather conditions, with reduced reliability and potentially faulty operation in extreme weather. A qualitative relationship between track circuits and weather patterns has been established in previous work but not quantified. In this paper, data collected from track circuits using amonitoring system is used to investigate the quantitative relationship between track circuit performance and weather conditions using linear regression model. The conclusions may be useful for understanding how the parameters of track circuits may take on various values during installation or maintenance that should be considered.

INTRODUCTION

Track circuits are designed to detect the presence of a train within a section of track, this information being an essential part of the railway signalling system [1]. The audio frequency track circuit (AFTC) is one of the most popular track circuit types. Most of the parameters in AFTCs are tuned during the initial installation, however because track circuits contain some outdoor components (e.g. running rails, tuning units), the performance of track circuit always change with ambient conditions. Examples include: leaf residue during the leaf fall season or a rolled rust layer on rails, preventing the track circuit from being adequately shunted by the wheelsets; blocked drainage causing the ballast leakage to increase [2].

If the influence of weather condition on track circuits is known, it might be helpful in adjusting the parameters of the track circuits during installation. What is the qualitative and quantitative relationship between the performance of track circuit and the weather conditions? Initial research into this question has been done some years ago [3], but further analysis need to be done.

This paper aims to explore the quantitative relationship between track circuit performance and weather conditions using linear regression model.

THE EFFECTS OF TEMPERATUREON AFTCS

There are many kinds of track circuits in railway lines all over the world. The AFTC is the most popular choice, particularly for electrified lines. The railway lines which use AFTC benefit from: operation on continuously welded (no joints) track which increases the comfort of passengers; high levels of immunity to AC or DC track current interference; information can be transmitted from the wayside into the train cab.

An AFTC generally comprises a transmitter, tuning units, and a receiver. The transmitter and receiver are connected to the two ends of a track circuit via tuning units that incorporate an isolating transformer and other passive components inside. The FSK signal, provided by the transmitter, passes along the track and reaches the receiver unless the rails are shunted by a wheelsets of train. The carrier frequency, modulation frequency and the amplitude of the FSK signal are examined in the receiver to prove that the track section is clear, otherwise the track section is flagged as occupied [4].

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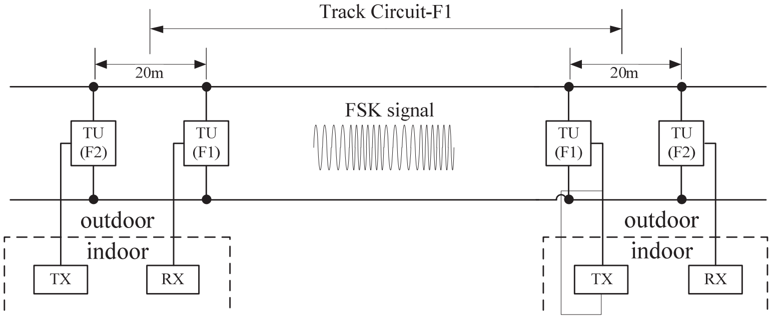

FIGURE 1. The components of TI21 track circuits.

A TI21 track circuit is one type of AFTC. As shown in Figure 1, the electrical separation of sequential track circuits is arranged by track tuning units (TUs). Tuned circuits present short circuits and resonant sections at different frequencies. The transmitter (TX) and receiver (RX) are installed under cover either in specially constructed buildings or in location cabinets. TUs are installed between the running rails.

In order to obtain the impact on track circuits from weather conditions, a monitoring system was developed and installed at Radyr in Wales UK. Measurements from two sequential track circuits were recorded for more than one year. The layout of measurement positions are shown in Figure 2, and the details of this system is described in more detail in [3].

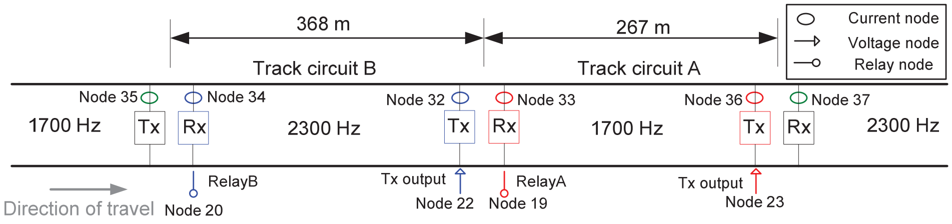

FIGURE 2. The sensor node setup at the test site in Wales

Recorded quantities include: the output voltages of two transmitter units; the currents in six tuning unit cables; and the outside temperature. The measurement nodes were designed to monitor the RMS value of a signal over a narrow band of frequencies with the centre frequency of the band continually being swept from about 1500 to 3500 Hz. In this way, the frequency content of a voltage or current were recorded about once per second. From the recorded data, the measurements can be obtained in a post-processing stage. Table 1 shows the description of each measurement point.

TABLE 1. Testing nodes description.

Node id	Symbol [Unit]	Node description
17	T [°C]	Temperature
19	RA [Pick/drop]	Relay state of track circuit 'A'
20	RB [Pick/drop]	Relay state of track circuit 'B'
22	VTXB [V]	TX output voltage of track circuit 'B'
23	VTXA [V]	TX output voltage of track circuit 'A'
32	ITXB [A]	TX tuning unit current of track circuit 'B'
	IRXTA [A]	RX terminating current of track circuit 'A'
33	IRXA [A]	RX tuning unit current of track circuit 'A'
	ITXTB [A]	TX terminating current of track circuit 'B'
34	IRXB [A]	RX tuning unit current of track circuit 'B'
35	IRXTB [A]	RX terminating current of track circuit 'B'
36	ITXA [A]	TX tuning unit current of track circuit 'A'
37	ITXTA [A]	TX terminating current of track circuit 'A'

DATA PROCESSING

To obtain the quantitative relationship between the performance of AFTC and temperature, 3635 observations when the rainfall is zero are extracted from the total 4127 observations. As shown in Figure 3(a), the scatter plots of VTXA against temperature which displayed in points are approximately linear with temperature. So a simple linear regression model described below is selected to estimate the quantitative relationship.

$$\hat{y} = \hat{a} + \hat{b}_t T \tag{1}$$

Where $\hat{y}$ represents a measured output of the track circuit, T indicates temperature, $\hat{a}$,$\hat{b}_t$ is the intercept and the slope respectively.

The regression fitting line of VTXA against temperature is also shown in Figure 3(a) in dashed line. But the scatter plots do not concentrate along the regression fitting line, and distribution of levels (this is because the quantisation resolution of the VTXA data is only 100 mV). So the mean values in every 0.5°C temperature interval (the sampling quantisation of temperature is 0.1°C) are calculated and shown in Figure 3(b) with points. Using these mean values, the regression fitting line of VTXA against temperature is calculated again and shown in Figure 3(b) in solid line. The upper and lower bounds on 95% confidence level are shown with dotted and dash dot in Figure 3(b) respectively. It is shown that most of the mean points are in the limit between upper and lower bounds. The results of track section 'B' follow a similar pattern, and are shown in Figure 3(c)-(d).

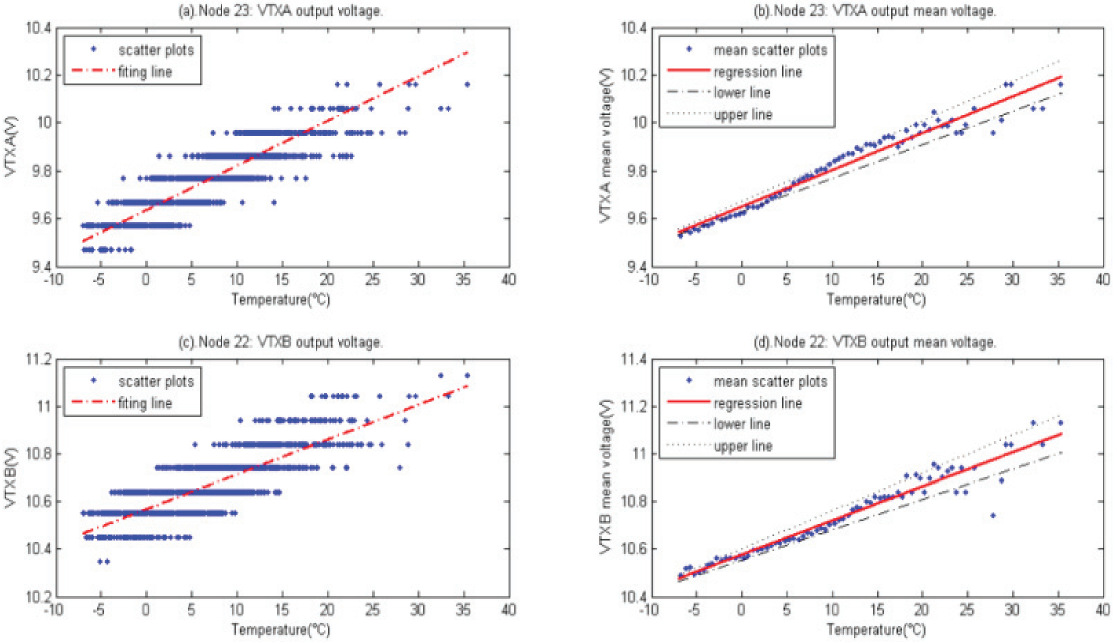

FIGURE 3. The scatter plots against temperature and the straight regression lines.

For TX tuning unit current ITXA, RX tuning unit current IRXA, TX terminating current ITXTA, because the method is the same as the method used in processing TX output voltage VTXA. So the results are not displayed in Figure 3 but are shown in Table 2. The details in Table 2 include the regression coefficients, intercepts and other results calculated on 95% confidence level using Matlab.

TABLE 2. The results of sample linear regression using temperature.

Output	$\hat{a}$	$\hat{b}_t$	**Variation (20°C)**	**Variation percent**	**F**	**r**	**Regression significance**	**Linear strength**
VTXA	9.651	0.0153	0.31 V	3.2%	1481	0.9772	Yes	Strong
ITXA	15.570	0.0005	0.01 A	0.06%	1	0.1338	No	Weak
IRXA	5.333	-0.0058	0.12 A	2.2%	258	-0.8870	Yes	Strong
ITXTA	13.654	-0.0010	0.02 A	0.15%	6	-0.2907	Yes	Weak
VTXB	10.578	0.0143	0.29 V	2.7%	1005	0.9670	Yes	Strong
ITXB	17.223	0.0108	0.12 A	1.3%	197	0.8587	Yes	Strong
IRXB	4.112	-0.0032	0.13 A	1.6%	39	-0.5975	Yes	Moderate
ITXTB	16.423	0.0087	0.17 A	1.1%	119	0.7933	Yes	Strong

The 'Variation' in Table 2 means the variation of the outputs when the temperature changes 20℃. The 'Variation percent' in Table 2 is the percent of variation to the intercept of regression straight line. The 'F' in Table 2 represents F-test value which is used to test the significance of the linear regression model. The 'Regression significance' leads to 'Yes' if the F value is greater than 3.84 ($F_{\alpha}(1, n-2) = F_{0.05}(1{,}3633) \approx F_{0.05}(1, \infty) = 3.84$) [5]. Otherwise it is 'No' which means the linear relationship is not significant. The 'r' is the correlation coefficient of the linear regression which is used to measure the direction and the strength of the linear regression. The 'Linear strength' means the strength of the linear regression, which results in 'Strong' if $|r| \geq 0.7$; results in 'Moderate' if $0.7 > |r| \geq 0.3$; results in 'Weak' if $0.3 > |r| \geq 0.1$; else results in 'None'.

From the data shown in Table 2, consider the F value and the correlation coefficient r together with the slope coefficient$\hat{b}$, we can find that: the linear regression model is suitable for the VTXA and VTXB, however, the others (ITXA, IRXA, ITXTA, ITXB, IRXB, ITXTB) do not change much with temperature.

CONCLUSION

Railway track and parts of a track circuit system are inevitably exposed to the local weather conditions. Some qualitative conclusions can be made on the basis of data taken over a long period of time from two real track circuits. Although the TX output voltage varied with temperature, the RX tuning unit current, which is the most critical part of an AFTC, does not change much with temperature.

Using linear regression model, the quantitative relationship between the output of an AFTC and the current and temperature has been obtained. These relationships are, of course, limited in application because the linear model is a gross simplification of the real behaviour of the system, and the coefficients of a linear model are likely to vary with local conditions such as ballast condition, the effectiveness of drainage and the length of the track circuit.

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