Detection of Track Circuit Signal Based on Digital Phase Frequency Descrimination

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Abstract
The cab signal plays an important position to guarantee the railway train operation safety and to improve the railway transport efficiency. Now, with the development of railway and the acceleration of train speed, the cab signal has been required as main rather than auxiliary cab signal as before. In view of this, the accurate and stable cab signal is a must in the process of running. Therefore, the analysis of waveform instantaneous frequency recorded on the recorder by means of the data processing system is an important means to solve the above problem and also a necessary and important task. In this case, this paper put forth to apply digital phase discrimination technology to the detection of frequency shift signal upper/lower side frequency and signal modulation lower frequency[3]. Compared with other methods, this method is characteristic of simple calculation and accurate and fast detection.
Key words: CAB SIGNAL, FREQUENCY SHIFT SIGNAL, MODULATION LOWER FREQUENCY

1. Introduction

Now, with the development of railway and the acceleration of train speed, the cab signal has been required as main rather than auxiliary cab signal as before. In view of this, the accurate and stable cab signal is a must in the process of running. However, in the current situation, the ground signal frequency drift often gives rise to the unstable cab signal, which will not only affect the train safety and the railway transportation efficiency but also present a great difficulty to cab signal equipment in terms of fault location and equipment maintenance due to randomness and uncertainty of the abnormal ground signal [4].

The cab signal recorder (hereinafter referred to as: recorder) is an important part of the cab signal equipment, including data board and cab signal recorder data processing system (hereinafter referred to as: data processing system) [5]. The recorder will take down on the data board the status information of the cab signal equipment at work as well as the waveform information of ground track circuit received by the cab signal inductor, and then display and analyze the information. Therefore, the analysis of waveform instantaneous frequency recorded on the recorder by means of the data processing system is an important means to solve the above problem and also a necessary and important task [6].

Frequency shift modulation FSK [7] belongs to nonlinear modulation, so signal spectrum can’t directly reflect its instantaneous frequency. In this case, this paper put forth to apply digital phase discrimination technology to the detection of frequency shift signal upper/lower side frequency and signal modulation lower frequency. Compared with other methods, this method is characteristic of simple calculation and accurate and fast detection.

2. Frequency shift signal and frequency spectrum

In terms of modulation, frequency shift signal belongs to FSK signal with continuous phase, and its corresponding mathematic expression is [2]

$$f(t) = A(t)\sin(\varphi(t)) = A(t)\sin(2\pi f_0 t + g(t)) \qquad (1)$$

Where,

$$g(t) = \begin{cases} 2\pi\Delta f t & 0 < t \le \dfrac{T_s}{2} \\ 2\pi\Delta f\left(\dfrac{T_s}{2} - t\right) & \dfrac{T_s}{2} \le t < T_s \end{cases} \qquad (2)$$

It is a triangle wave periodic function on a T_s cycle, namely, $g(t) = g(t \pm nT)$, where its frequency is f_s, that is, the signal modulation lower frequency, the corresponding instantaneous frequency of which is:

$$v_f = \begin{cases} f_0 + \Delta f = f_h & 0 < t \le \dfrac{T_s}{2} \\ f_0 - \Delta f = f_l & \dfrac{T_s}{2} \le t < T_s \end{cases} \qquad (3)$$

Frequency shift signal diagram is shown in Figure 1, where $A(t)$ refers to signal amplitude envelope, f_0 is signal carrier frequency, f_h and f_l are the signal upper/lower side frequency, and Δf is signal frequency offset. It is thus clear that as far as frequency shift signal is concerned, its corresponding information features mainly involve: modulation lower frequency, upper/lower side frequency and information envelope.

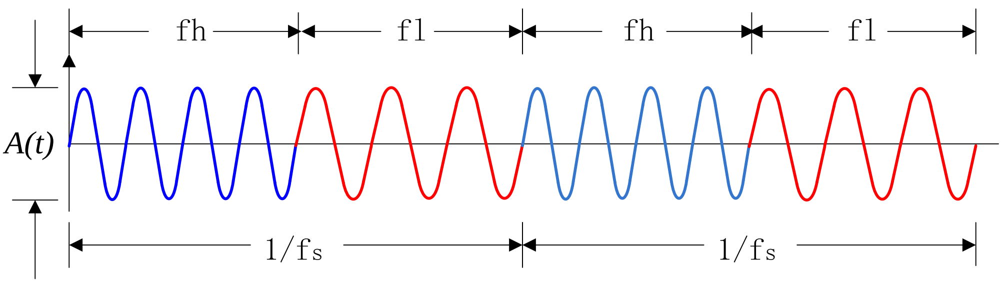

Figure 1. Frequency shift signal diagram

The frequency offset of the frequency shift signal is defined as $\Delta f = \pm 55\text{Hz}$. Table 1 shows its corresponding carrier frequency and side frequency.

Table 1. Homemade 4 information frequency shift signal carrier frequency and upper/lower side frequency

Operation direction	Carrier frequency	Lower side frequency	Upper side frequency
Up link	650	595	705
	850	795	905
Down link	550	495	605
	750	695	805

The spectrum of the frequency shift signal is expressed as:

$$\begin{aligned} F = \\ & I_0 \frac{2m}{n}\left\{\frac{1}{m^2}\sin\left(\frac{m^2}{2}\right)\cos\omega_0 t + \frac{1}{m^2-1}\cos\left(\frac{m^2}{2}\right)[\cos(\omega_0-\omega_s)t - \cos(\omega_0+\omega_s)t]\right. \\ & -\frac{1}{m^2-2}\sin\left(\frac{m^2}{2}\right)[\cos(\omega_0-2\omega_s)t + \cos(\omega_0+2\omega_s)t] \\ & \left.-\frac{1}{m^2-3^2}\cos\left(\frac{m^2}{2}\right)[\cos(\omega_0-3\omega_s)t - \cos(\omega_0+3\omega_s)t]......\right\} \end{aligned} \qquad (4)$$

Where, m is the coefficient of frequency modulation (FM), equal to $\Delta\omega / \omega_s$, ω_0 is the angular frequency of the carrier frequency, and ω_s is the angular frequency of modulation lower frequency.

Seen from (4), the spectrum of frequency shift signal as a kind of nonlinear modulation signal has the following characteristics: it is discrete line spectrum, and has two sides with the carrier frequency of the frequency shift signal as the center. The upper and lower sides are harmonic waves of modulation lower frequency. Therefore, the modulation lower frequency of frequency shift signal can be directly calculated from the frequency shift spectrum. Modulation coefficient m of the frequency shift signal is mostly not integer, so there are no spectral lines along the upper and lower side frequency in the frequency shift signal spectrum. That is, the frequency value of the signal upper and lower side frequency cannot be directly obtained just by means of the frequency shift signal spectrum analysis.

3. Frequency measurement principle of digital phase discrimination method

As usual, let the measured signal be:

$$S(t) = A\sin(\omega_0 t + \alpha) \quad (5)$$

After the switching of sampling cycle T, the value for the i-th sampling point is:

$$S_i = A\sin(\omega_0 Ti + \alpha) \quad (6)$$

Let U_i and V_i be the signal values of the same signal at different sampling points and define the step factor as j, then V_i is the i-th point and U_i is the (i + j)-th point, namely:

$$\begin{cases} U_i = S_{i+j} \\ V_i = S_i \end{cases} \quad (7)$$

Then define the instantaneous phase discrimination factor P_i as:

$$P_i = U_i V_{i+1} - U_{i+1} V_i = S_{i+j} S_{i+1} - S_{i+j+1} S_i \quad (8)$$

$$\begin{aligned} P_i &= A\sin(\omega T\left(i+j\right) + \alpha) A\sin(\omega T(i+1) + \alpha) \\ &\quad - A\sin(\omega T(i+j+1) + \alpha) A\sin(\omega Ti + \alpha) \\ &= A^2 \sin(\omega Tj)\sin(\omega T) \end{aligned} \quad (9)$$

Namely:

$$P_i \propto \sin(j\omega T) \quad (10)$$

By (10), the instantaneous phase discrimination factor is proportional to the signal phase difference sine at the j-th sampling cycle. To eliminate other proportion factors in (10), calculate the quotients of corresponding phase discrimination factors of different step factors respectively and work out the corresponding signal frequency with anti-trigonometric function transformation. For example, let j = 1, 2 respectively to obtain the signal frequency by (11) and (12).

$$\frac{P_{j=2}}{P_{j=1}} = 2\cos(\omega T) \quad (11)$$

$$\omega = \frac{1}{T}\arccos\left(\frac{P_{j=2}}{2P_{j=1}}\right) \quad (12)$$

Thus, if let j = 1, 2, then by (8), (11) and (12), the signal frequency can be calculated on the basis of only a few sampling points of the measured signal, which has superb instantaneity.

4. Frequency shift signal frequency detection

4.1Detection scheme

As shown in Figure 2, according to the ground information recorded on the recorder through the signal machine, divide frequency shift signal waveforms into block sections. Frequency shift signal frequency detection within each block section mainly involves the following four parts:

(1) Use the band-pass filter to filter interference outside the frequency shift signal band pass.

(2)Calculate the signal upper and lower side frequency with the digital phase discrimination technology.

(3)Estimate the frequency that each block section sends the frequency shift signal according to the upper/lower side frequency calculation results, along with the automatic block section information.

(4)Calculate the frequency of signal modulation low frequency according to the upper/lower side frequency calculation results.

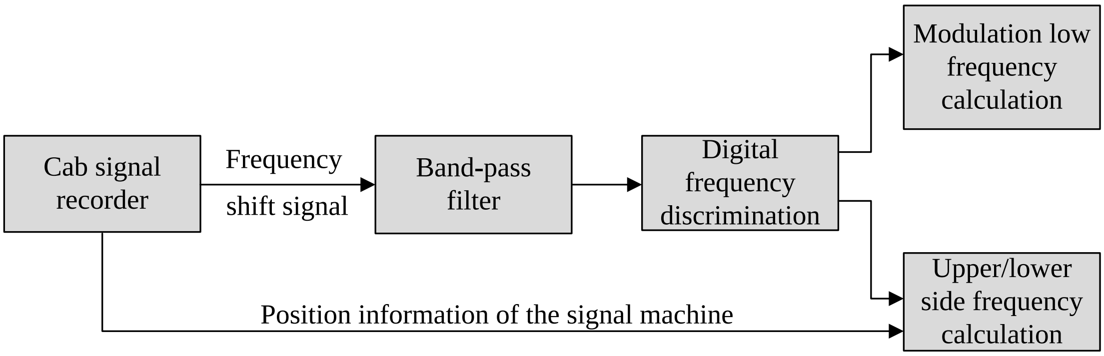

Figure 2. Block diagram of frequency shift signal frequency detection principle

4.2 Step factor j selection

In view of the presence of signal noise, when phase discrimination signal noise is irrelevant, the expectation of the error is zero, but, when j equals to 1, (8) has quadratic components at the same point, whose noise square expectation is not zero, thus avoid j =1. Instantaneous phase discrimination factor is proportional to $\sin(j\omega T)$, when the absolute value of $\cos(j\omega T)$ is close to 1, $\sin(j\omega T)$ gets so small that the absolute value of the instantaneous phase discrimination factor gets small, too, which increases the relative effect of noise rather than diminish its effect and thus results in greater error. In addition, when the absolute value of $\cos(j\omega T)$ is close to 1, as its reciprocal gets small enough to introduce greater error by calculating its anti-trigonometric function to get the frequency. So, in case of error reduction, a reasonably selection of j will make $j\omega T$ far from the integral multiples of π.

Table 2. $\sin(j\omega T)$ of frequency shift signal step factors

	550		750		650		850	
	495	605	695	805	595	705	795	905
$\cos(\omega T)$	0.9254	0.8892	0.8928	0.8506	0.8547	0.8067	0.8113	0.7578
$\sin(2\omega T)$	0.7015	0.8136	0.8874	0.9535	0.8044	0.8945	0.9486	0.9889
$\sin(3\omega T)$	0.9193	0.9895	0.9978	0.9474	0.9858	0.9959	0.9546	0.8464
$\sin(4\omega T)$	0.9999	0.9461	0.8181	0.5750	0.9558	0.7997	0.6004	0.2940
$\sin(5\omega T)$	0.9312	0.6931	0.4008	-0.0196	0.7209	0.3645	0.0196	-0.4008
$\sin(6\omega T)$	0.7236	0.2865	-0.1331	-0.6067	0.3313	-0.1797	-0.5686	-0.9015
$\sin(7\omega T)$	0.4079	-0.1835	-0.6283	-0.9592	-0.1292	-0.6701	-0.9422	-0.9656
$\sin(8\omega T)$	0.0314	-0.6129	-0.9409	-0.9409	-0.5621	-0.9603	-0.9603	-0.5621

Table 2 shows $\sin(j\omega T)$ of frequency shift signal upper/lower side frequency when the step factor j value varies. Seen from Figure 2, only when $j=2$ and $j=3$, $\sin(2\omega T)$ and $\sin(3\omega T)$ of the frequency shift signal upper/lower side frequency are relatively average and greater than 0.7, which is in line with the principle of step factor selection. In this case, the frequency shift signal instantaneous frequency should be estimated by (13) and (14).

$$Y=\frac{P_{(j=3)}}{P_{(j=2)}}=\frac{\sin(3\omega T)}{\sin(2\omega T)}=\frac{4\cos^2(\omega T)-1}{2\cos(\omega T)} \quad (13)$$

$$\omega=\frac{1}{T}\arccos\left(\frac{Y+\sqrt{Y^2+4}}{4}\right) \quad (14)$$

5. Actual detection

It is a simulation signal of a length of track circuit which is shown in figure 3.Where, the signal amplitude is 1v, the signal carrier frequency is 750Hz, the modulation low frequency is 15Hz, the sampling frequency is 8000Hz, and the total signal point is 4000.

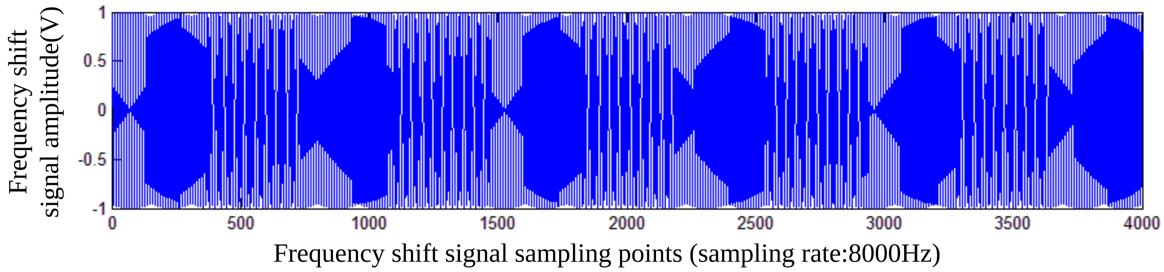

Figure 3. Simulation signal of a length of track circuit

The upper/lower side frequency simulation result is shown in figure4 after analysing the signal shown in figure3 by using the algorithm shown in figure2.It is shown from the figure that the instantaneous frequency of the track circuit can be quickly got by using the method of this paper. Where, the upper side frequency is 805Hz ,the lower side frequency is 695Hz, the error is zero. The signal modulation lower frequency of the track circuit can be got based on the transformation of upper\lower side frequency shown in figure 4.Compared with the simulation of figure3, the estimation of upper/lower side frequency and signal modulation lower frequency is correct by using the method in this paper.

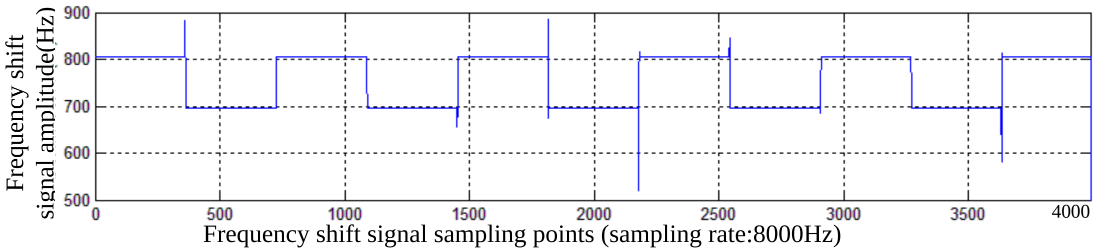

Figure 4. The transformation result of the upper/lower side frequency by using the method of this paper to analyze Figure 3

Moreover, it is worth noting that there will be false frequency which is inconsistent with the actual situation in the junction of the upper/lower side frequency, according to formula(3),it is mainly owing to the mutation of the upper/lower side frequency at this point, then the mutation affects formula(13)、(14) for the result of the false frequency, but the influence is only limited at the mutation point. So it is easy to eliminate the point.

6. Conclusion

This paper put forth to apply digital phase discrimination technology to the detection of frequency shift signal upper/lower side frequency and signal modulation lower frequency. Compared with other methods, this method is characteristic of simple calculation and accurate and fast detection,test proves that, this method can provide the unified, accurate and high efficient analysis means to cab signal application unit of the railway site of the whole country.

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