Solution to Harmonics Interference on Track Circuit Based on ZFFT Algorithm with Multiple Modulation

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ABSTRACT: *The interference with the track circuit signal is more and more complex under the condition of high-speed and heavy haul, how to detect the signal parameters of track circuit more accurately is becoming an important issue. Firstly, the harmonic interference of the traction current is analyzed, and the harmonic current component of the traction current under the consideration of the power frequency drift and actual measurement are given. Then, due to the track circuit frequency shift signal (FSK signal) uses the frequency parameters to transmit control information. Therefore, through improving the spectrum resolution to improve the reliability of the signal detection, and combing the advantages of ZFFT (Zoom Fast Fourier Transform) algorithm with multiple modulation in the field of signal spectrum local refinement, the ZFFT algorithm with multiple modulation is proposed to detect the frequency signal of the track circuit. This algorithm refines the interested local signal spectrum of the whole signal spectrum to improve the spectral resolution, which can find and eliminate the interference signal frequency. Finally, the simulation is carried out, and the simulation results show that the frequency shift signal detected by this method can meet the error standard of signal detection and improve the reliability of track circuit signal detection.*

Key words: Track Circuit, Frequency Shift Keying Modulation, Zoom Fast Fourier Transform, Multiple Modulation, Spectrum Resolution

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1. Introduction

ZPW-2000 joint less track circuit is the core of frequency shift automatic block system, and its normal operation is the basis of ensuring the normal operation of the railway signal system[1]. At present, the conductive interference produced by the unbalanced traction current on the rail may severely influence track circuit[2]. In order to ensure the transportation safety of railway systems, the indexes of anti electric interference are set according to the electromagnetic interference under the most unfavorable conditions. Generally, the disturbed equipment of track circuit must be able to work reliably under the interference condition of the 10% unbalanced coefficient of the traction current[3]. The capacity of traction current is 1000A for high speed railway in China, the corresponding unbalanced traction current is 100A; the capacity of traction current is 1600~2000A for heavy haul railway in China, and the corresponding unbalanced traction current is 160~200A. Therefore, with the increase of the traction current, the unbalanced traction current is also increasing, and the conductive interference will be coupled into the frequency shift signal receiving equipment, which will affect the reliable demodulation of frequency shift signal and threat the safe operation of the train[4].

The magnitude of the unbalanced traction current is determined by the traction current in the rail and the unbalance degree of the rail. The unbalance traction current includes the 50HZ fundamental wave, there are also DC and abundant harmonic components. Many scholars have conducted in-depth research on the conductive interference caused by the unbalance traction current on track circuit. The British Standard Organization RSSB (Rail Safety and Standards Board) developed a detailed protection rule for the electric power frequency interference of communication equipment[5]. For ZPW-2000 track circuit in station, Xiaochun Wu put forward a specific protection scheme for the interference of electrified pulse current[6]. Xuecheng Qian put forward protective measures for the interference problem of the DC component of the unbalance traction current on the 25HZ phase sensitive track circuit[7]. At present, the relevant standards of railway system only stipulated the unbalance coefficient of traction current. Therefore, the content of each experimental measurement mainly focused on the measurement of unbalance coefficient, namely the measurement of the equivalent current at the power frequency, so the measurement and research of the harmonic current are less.

ZPW-2000 track circuit frequency shift signal adopts FSK (Frequency Shift Keying) modulation mode[9], the main parameters are carrier frequency0low frequency and frequency deviation. The four carrier frequencies (f_0) include 1700HZ, 2000HZ, 2300HZ, 2600HZ. There are 18 low frequency that represent train speed information, ranging from 10.3HZ to 29Hz with equal interval (1.1Hz) and representing a kind of control information for one low frequency[10]. The frequency deviation and the filter bandwidth are f_0±11HZ and f_0±40HZ respectively[11]. Under the condition of high-speed and heavy haul railway, (1) as the traction current continues to increase, the immunity indexes of the in-band harmonics of the receiver filter also increased; (2) the requirements of the carrier and low frequency error are not greater than ±0.15HZ and ±0.03HZ respectively, and thus the spectrum resolution of the frequency domain demodulation has higher requirement[12]. The high speed railway adopts the TCC (Train Control Center) to encode for the track circuit, so it is necessary to decode the modulation signal accurately and timely. Therefore, it is necessary to study the protection of harmonic interference for ZPW-2000 track circuit.

The transmitter and receiver of ZPW-2000 track circuit adopt AD (Analog-to-Digital) and advanced DSP technology[13]. Due to the significant spectrum characteristics of FSK signal, the classical methods such as FFT (Fast Fourier Transform) and spectrum analysis have been applied. Based on the comprehensive analysis of the advantages and disadvantages of various methods, the ZFFT algorithm with multiple modulation has significant advantages in terms of analysis accuracy, computational efficiency, resolution and flexibility, and put forward the idea of applying it to the detection of track circuit signals.

2. Harmonic Interference Analysis of the Traction Current

The traction current and frequency shift signal current are transmitted through the rail, the traction current not only includes 50HZ and DC components, but also has the harmonic components, which frequencies are integer multiple of 50HZ. when the frequency shift signal transmission in the track circuit, which will be affected by the harmonic components of the traction current[14]. When analyzing the component of the traction current, the in-band harmonics of the signal should be paid more attention. According to the relevant technical conditions, the immunity limit of SIR (signal to interference ratio) for ZPW-2000 track circuit is 1:1. In order to protect the electrified harmonics, the reception band of frequency shift signal of the ZPW-2000 track circuit is f_0± 40HZ. Therefore, under normal conditions, only single harmonic that at the carrier frequency band (1700/2000/2300/2600HZ) can enter the pass-band and affect the reliable demodulation of the signal[15]. And the use of time domain filtering to eliminate in-band interference is very difficult.

Under the condition of high speed and heavy haul railway, with the increase of traction current, the harmonic interference current will increase correspondingly, assuming that the harmonic ratio is constant. The influence of harmonic current on the reliable demodulation of track circuit signal is explained by the actual test data[16]. The harmonic distribution ratio in the frequency range of track circuit is shown in Table 1. The test conditions were as follows: the running direction of the locomotive was upward, the carrier frequency of the track circuit was 2600HZ, the speed was about 50km/h, and the unbalanced traction current of the rail was about 190A.

Frequency(HZ)	Amplitude(mV)	Proportion(%)	Frequency(HZ)	Amplitude(mV)	Proportion(%)
1650	25.20	1.9202	2200	4.78	0.3642
1700	9.73	0.7414	2250	39.70	3.0251
1750	63.74	4.8569	2300	9.31	0.7094
1800	13.45	1.0249	2350	13.32	1.0150
1850	45.78	3.4883	2400	11.51	0.8770
1900	2.10	0.1600	2450	21.35	1.6282
1950	23.82	1.8150	2500	6.16	0.4694
2000	9.77	0.7445	2550	74.23	5.6562
2050	46.92	3.5752	2600	132.35	10.0848
2100	7.26	0.5532	2650	36.91	2.8125
2150	60.87	4.6382	2700	12.30	0.9372

Table 1. The distribution ratio of signal and each harmonic

According to the data in the table, it can be seen that the overall distribution of the harmonic components decrease with the increase of the frequency. Therefore, the harmonics are relatively small in the frequency band of ZPW-2000 signal. As the test train ran at the carrier frequency of 2600HZ, where the harmonic current at 2600HZ was superimposed the frequency shift signal of the same frequency, so the test data ratio was higher at 2600HZ, so the harmonic current at the 2600HZ could not be considered as interference current.

According to the data in Table 1, ignoring the signal of 2600HZ and harmonic interference, the harmonic and signal current value at the three carrier frequencies of the track circuit in the case of the maximum unbalanced traction current 200A are shown in Table 2. The current value of the frequency shift signal is referenced to the reliable work value that specified in the Railway Signal Maintenance Rules[17], and 500mA is taken as the reference value.

Frequency(HZ)	Signal current(mA)	Maximum current(mA)	Interference current(mA)	SIR
1700	500	1482.8	741.4	0.674
2000	500	1489	744.5	0.672
2300	500	1418.8	740.9	0.675

Table 2. Comparison of harmonic and signal current

As shown in Table 2, the SIR is obviously less than 1, and the energy of the harmonic interference is probably greater than the energy of the frequency shift signal. When the traction current fundamental wave and harmonic wave are discussed, they are considered according to the ideal situation, but the fact is not the case. According to the national standard GB/T 15945-2008 “Power quality-Frequency deviation for power system”, the power frequency deviation range is 50 ± 0.5HZ, that is ±1%[18], the corresponding higher harmonic current frequency will also drift. The part of the higher harmonic current frequency drift range as shown in Table 3.

No drift	Low-end	High-end	No drift	Low-end	High-end	No drift	Low-end	High-end
500	495	505	850	841.5	858.5	2050	2029.5	2070.5
550	544.5	555.5	900	891	909	2250	2227.5	2272.5
600	594	606	1650	1633.5	1666.5	2300	2277	2323
650	643.5	656.5	1700	1683	1717	2350	2326.5	2373.5
700	693	707	1750	1732.5	1767.5	2550	2524.5	2575.5
750	742.5	757.5	1950	1930.5	1969.5	2600	2574	2626
800	792	808	2000	1980	2020	2650	2623.5	2676.5

Table 3. The high-end and low-end frequency of the in-band harmonics after the fundamental frequency drift of the traction current

ZPW-2000 track circuit uses a crystal that independent of the power supply frequency as the signal frequency source[19], that is, the pass-band of filter does not change with the drift of fundamental wave. Therefore, the harmonic frequency drift may deteriorate the SIR. The pass-band of ZPW-2000 receiving filter is $f_0 \pm$ 40HZ, for example, the pass-band of carrier frequency 1700HZ is 1660 ~1740HZ, and only the 34th harmonic 1700HZ of 50HZ can enter the pass-band. Considering the frequency drift (±1%), it is possible that two harmonic frequencies can enter the signal receiving pass-band simultaneously. That is, the higher harmonic interference at frequencies of 1683HZ and 1717HZ will enter the receiver with a pass-band of 1700 ± 40HZ, as shown in Figure 1.

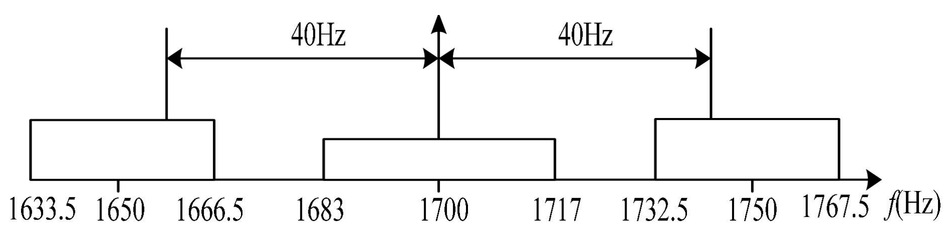

Figure 1. The schematic diagram of harmonic interference at 1700HZ

According to the measured data in Table 1, the corresponding in-band harmonic interference current can be obtained as shown in Table 4.

Frequency(HZ)	Interference current(mA)	Frequency(HZ)	Interference current(mA)	Frequence(HZ)	Interference current(mA)
1650	1920.2	1700	741.4	1750	4856.9
1950	1825	2000	744.5	2050	3575.2
2250	3025.1	2300	740.9	2350	1015

Table 4. The in-band harmonic interference current data

Obviously, when the out-off-band harmonic goes into the pass-band, it will significantly exceed the reliable value of the frequency shift signal current. If two harmonics interference are considered simultaneously, the resultant harmonic will be larger. Taking 1650HZ and 1700HZ into the signal pass-band as an example, the resultant harmonic current is $\sqrt{1920.2^2 + 741.4^2}$ = 2058.36 *mA*. The reliable operation value of frequency shift signal is 500mA, and the SIR is 1:4.12. Therefore, when the power frequency drift of the traction current occurs, the energy of the traction current conductive interference greatly exceeds the signal strength of the track circuit, so that the FSK signal is submerged by interference, the position of the in-band harmonic overlaps with the signal spectrum, and the signal spectrum structure is damaged, which cause wrong decisions of ground and locomotive signal reception.

3. FSK Signal Characteristics and Demodulation Methods

ZPW-2000 track circuit adopts FSK modulation mode. The spectrum of FSK signal $s(t)$ consists of the carrier frequency and side frequency ω_0-nω_1 and ω_0+nω_1 [20]:

$$
\begin{aligned}
&(FFT(s(t))) = \frac{2A_0}{\pi}\{\frac{1}{\mathrm{m}}\sin(\frac{m\pi}{2})\cos(\omega_0 t) \\
&\sum_{k=1}^{\infty}(-1)^k \frac{m}{m^2-(2k-1)^2}\cos(\frac{m\pi}{2})[\cos(\omega_0-(2k-1)\omega_1)t-\cos(\omega_0+(2k-1)\omega_1)t] \\
&+\sum_{k=1}^{\infty}(-1)^k \frac{m}{m^2-(2k)^2}\sin(\frac{m\pi}{2})[\cos(\omega_0-2k\omega_1)t+\cos(\omega_0+2k\omega_1)t]\}
\end{aligned}
\tag{1}
$$

Where, ω_0 is the carrier frequency, ω_1 is the modulation frequency, $m=\Delta\omega/\omega_1=\Delta f/F_1$ is the coefficient of frequency modulation, $\Delta\omega(\Delta f)$ is the frequency deviation, $F_1(\omega_1)$ is the low frequency.

It can be seen from the analysis that the spectrum in the frequency domain modulated by square wave and continuous phase frequency shift wave is a set of discrete spectrum line. The middle part is the carrier frequency component ω_0 ($n = 0$), the left-side frequency component are $\omega_0 - n\omega_1$, the right-side frequency component are $\omega_0 + n\omega_1$ (n =1,2,3...), and the distance between the frequency components is ω_1, and the relative amplitude between the spectrum lines is shown in Table 5.

Frequency component	Relative amplitude
Carrier frequency	$\frac{2}{m\pi}\sin(\frac{m\pi}{2})$
Side-frequency(n is odd)	$\frac{2m}{\pi(m^2-n^2)}\cos(\frac{m\pi}{2})$
Side-frequency(n is even)	$\frac{2m}{\pi(m^2-n^2)}\sin(\frac{m\pi}{2})$

Table 5. The relative amplitude of FSK signal spectrum

As the modulation coefficient m changes, the magnitude of each spectrum line in the frequency domain of the frequency shift keying wave will change. When the frequency deviation Δf is fixed, the modulation coefficient will decrease as the modulation low frequency F_1 increases. Under the condition of the same carrier frequency, the spectrum distribution of frequency shift wave with different modulation coefficients is different. For example, considering the track circuit carrier frequency 1700HZ, the spectra of modulation frequency 19.1HZ and 11HZ are respectively calculated and shown in Figure 2. and Figure 3.

It can be known from the figure that the FSK signal is narrow band signal, and the method of frequency domain processing can be considered to eliminate the harmonic interference. The advantages of frequency domain analysis are as follows: (1) The out-off-band interference can be easily eliminated in frequency domain. (2) The distribution of the harmonic components of unbalanced traction current in the frequency domain is a set of spectrum lines with 50HZ interval, which is significantly different from the FSK signal. (3) The ZFFT algorithm can be used to refine the signal spectrum that need to be carefully analyzed to improve the spectral resolution of this segment, so that the interference signal can be reliably identified and eliminated.

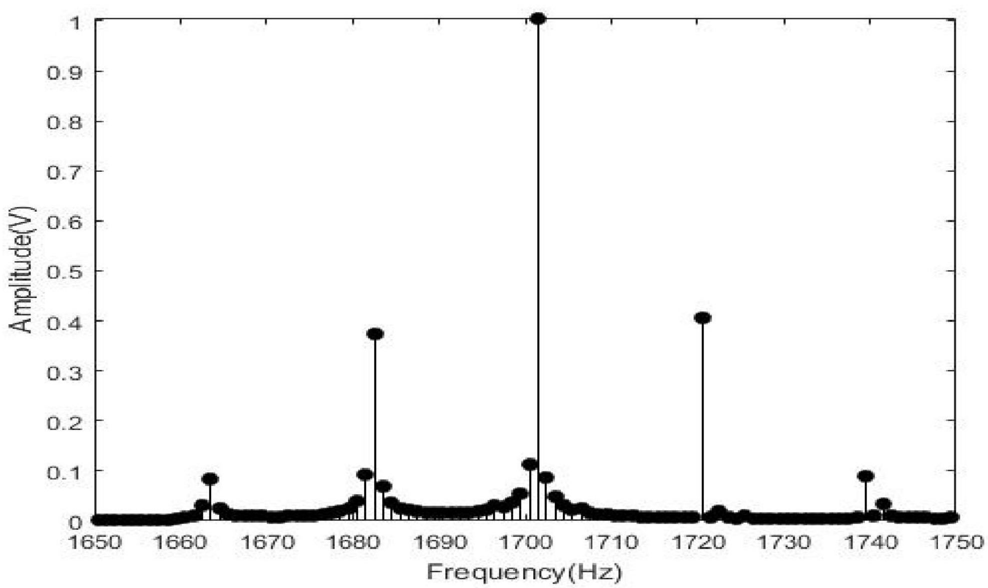

Figure 2. Spectrum of modulation frequency 19.1HZ

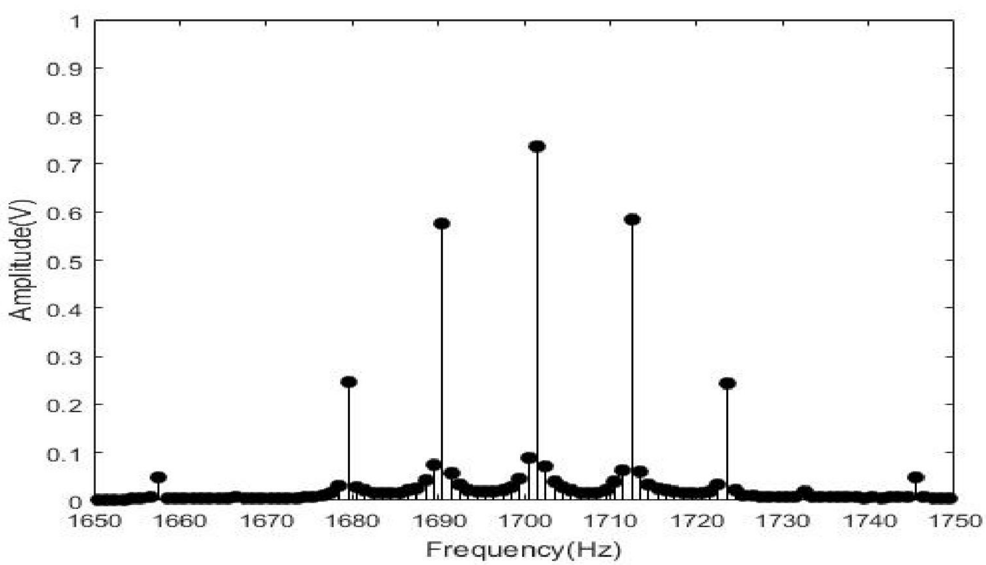

Figure 3. Spectrum of modulation frequency 11HZ

4. Basic principles of ZFFT Algorithm with Multiple Modulation

The processing of ZFFT algorithm with multiple modulation is: frequency shift → low pass digital filter → resample → FFT process and spectrum analysis → frequency adjust[21], the schematic diagram as shown in Figure 4.

The discrete signal $x_0(n)(n=0, 1, \ldots, N-1)$ can be got from analog signal $x(t)$ by the processing of anti aliasing filtering and A/D sampling, setting f_s is sampling frequency, $f_1 \sim f_2$ is the frequency band of requiring refinement, f_e is the center frequency of requiring refining frequency band, D is the times of refinement. The algorithm process can be divided into five steps.

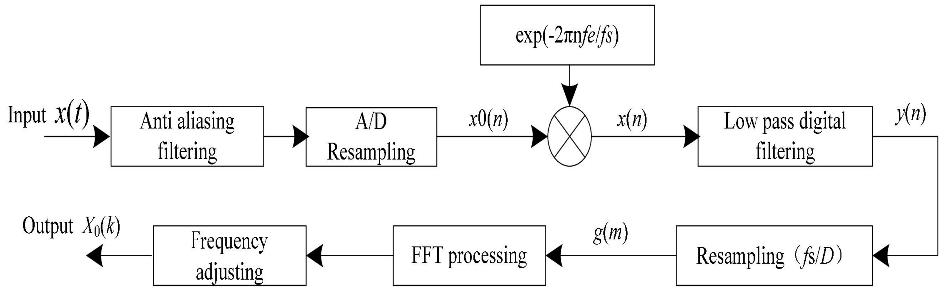

Figure 4. The schematic diagram of ZFFT algorithm

4.1 Frequency Shift of the Multiple Modulation

In order to improve the spectral resolution, it is proposed that shift the frequency spectrum of the signal to low frequency, so that it can sample with lower sampling frequency under the condition of satisfying the Nyquist principle and make the center frequency of requiring refining frequency band to become the zero frequency position of frequency domain coordinates. The fourier transform of discrete signal sequence $x_0(n)$ is shown in Eq. 2. Where, W_N is equal to $e^{-j2\pi/N}$.

$$X_0 = \sum_{n=0}^{N-1} x_0(n) W_N^{nk}, (k = 0, 1, 2, \ldots N-1) \tag{2}$$

According to the refining frequency range ($f_1 \sim f_2$), the refining band center frequency $f_e = (f_1+f_2)/2$ can be calculated. The signal $x_0(n)$ frequency is shifted by multiplying $e^{-j2\pi nfe/fs}$, the result $x(n)$ of shifting frequency is shown in Eq. 3.

$$x(n) = x_0(n)e^{-j2\pi nf_e/f_s} = x_0(n)\cos\frac{2\pi nf_e}{f_s} - jx_0(n)\sin\frac{2\pi nf_e}{f_s} \tag{3}$$

$$= x_0(n)\cos\frac{2\pi nL_0}{N} - jx_0(n)\sin\frac{2\pi nL_0}{N}$$

In Eq. 3, Δf is interval of spectrum line, $f_s = \Delta f N$ is sampling frequency, $L_0 = f_e/\Delta f$ is the shift position of frequency spectrum center, L_0 is also the spectrum line order number of center frequency of the whole frequency spectrum.

Setting $X(k)$ is the discrete frequency spectrum of $x(n)$, there can get Eq. 4.

$$X(k) = X_0(k + L_0) \tag{4}$$

The Eq. 4 represents that signal spectrum has been moved to the zero frequency position.

4.2 Low Pass Digital Filtering

The low pass digital filter with cut-off frequency $f_c = f_s/2D$ is used to achieve anti-aliasing filtering, in order to ensure that the resampling signal does not aliasing. D is times of frequency refining, the output of the filter is:

$$Y(n) = X(k)H(k) = X_0(k + L_0), (k = 0, 1, 2 \ldots N-1) \tag{5}$$

In Eq. 5, the $H(k)$ is response of ideal low pass filter. And the time-domain output of the filter is:

$$y(n) = \frac{1}{N}\sum_{k=0}^{N-1} Y(k) W_N^{-nk} = \frac{1}{N}\sum_{k=0}^{N-1} X(k)H(k)W_N^{-nk} \tag{6}$$

4.3 Resample

Through frequency shifting and low pass filtering, the maximum frequency of signal is reduced. Then using the lower sampling frequency $f'_s = f_s/D$ to resample the signal, the f'_s is D times smaller than the original sampling frequency. So the time domain expression is $G(m) = y(Dm)$, and according to the formula 2, 4, 5, the Eq. 7 can be got.

$$g(m) = \frac{1}{N}\left|\sum_{P=0}^{\frac{N}{2}} X_0(P+L_0)W^{-pm} + \sum_{P=\frac{N}{2}}^{N-1} X_0(P-N+L_0)W^{-pm}\right| \tag{7}$$

4.4 FFT Process

Through the FFT processing for resampling N point sequence, the N spectrum lines can be got. This spectrum lines frequency resolution is $\Delta f' = f'_s/N = f_s/ND = \Delta f/D$, so it is improved D times obviously, the $g(m)$ spectrum function can be got by using DFT.

$$G(k) = \sum_{m=0}^{N-1} g(m)W_N^{mk} = \begin{cases} \frac{1}{D} X_0(k+L_0), (k = 0,1,2,\ldots \frac{N}{2}-1) \\ \frac{1}{D} X_0(k+L_0-N), (k = \frac{N}{2}, \frac{N}{2}+1, \ldots N-1) \end{cases} \tag{8}$$

4.5 Frequency Adjustment

Moving the above spectrum line to the actual frequency position can get the refined processing frequency band, moving frequency function as Eq. 9.

$$X_0(k) = X(k-L_0) = \begin{cases} D*G(k-L_0), (k = L_0, \ldots \frac{N}{2}-1) \\ D*G(k-L_0+N), (k = L_0 - \frac{N}{2}, \ldots L_0 - 1) \end{cases} \tag{9}$$

Through the above five steps, the final analyze and processing result can reflect the original digital sequence spectral characteristics in a certain frequency range. Compared with the direct FFT of the same points, the frequency resolution obtained by above refining method is improved D times and the frequency shift signal can be reliably modulated.

5. Application of ZFFT Algorithm in Signal Detection of Track Circuit

In order to detect the reliable control information, the spectrum of the signal must satisfy certain resolution when detect the frequency shift signal of the track circuit. The track circuit signal detection needs to refine signal frequency spectrum of $f_0 \pm$ 40Hz[22], so this detection can be seen as a detailed viewing matter in a narrow band, the basic processing idea is to enlarge the frequency band that needed to be carefully observed. ZFFT algorithm with multiple modulation is proposed to apply on the track circuit signal detection. In the normal operation of the train, the locomotive signal receiving device only can decode for the frequency shift signal of the carrier frequency and get the frequency shift signal spectrum. The transmission information of signal can be got through the analysis of the spectrum lines distribution[23].

For example, the frequency shift signal of track circuit with the carrier frequency 1700-1(1701.4HZ), the modulation frequency 19.1Hz and the frequency deviation 11Hz is taken as the research object. The signal detection of ZFFT algorithm with multiple modulation is carried out. The steps are as follows.

5.1 Obtain Refining Frequency Band Range

This step is to determine the frequency band range of needing refining, through taking direct traditional FFT technology to process the research object. The sampling frequency f_s=8192HZ and the sampling point N=8192, therefore, the waveform and spectrum can be got, as shown in Figure 5.

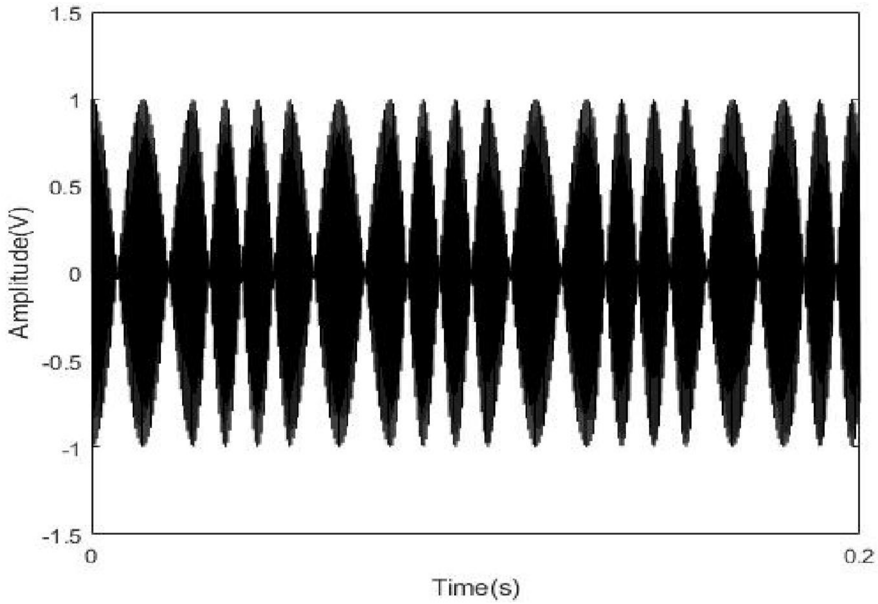

Figure 5(a). The time domain waveform of frequency shift signal

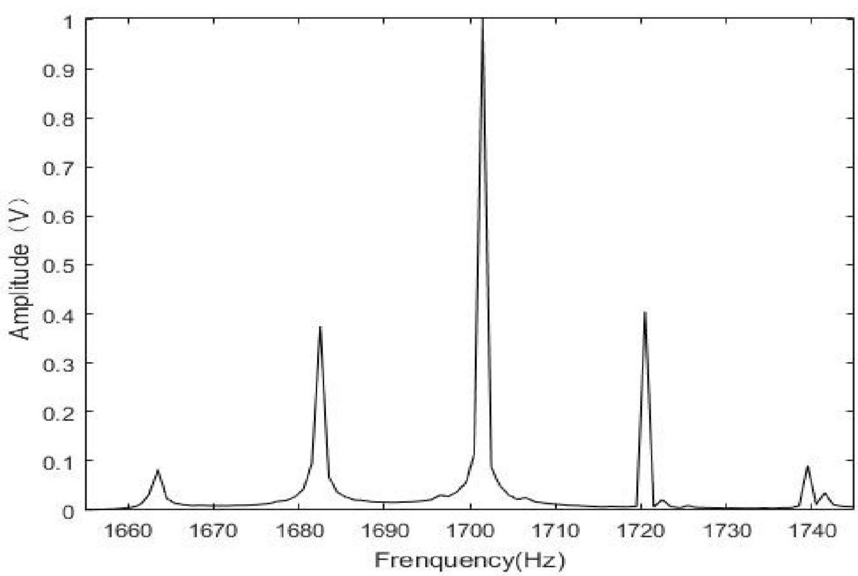

Figure 5(b). The spectrum of frequency shift signal

The refining frequency band range have four, respectively are 1700 ± 40Hz, 2000 ± 40Hz, 2300 ± 40Hz, 2600 ± 40Hz, so the carrier frequency of signal can be ensured in Figure 5. And the refining frequency band range of 1700 ± 40Hz can also be got.

5.2 Signal Multiple Modulation

This step is to move the needed refining signal frequency band of 1700 ± 40Hz to 0 ~ 80 Hz. Using $e^{-j2\pi nf1/fs}$ multiply the sampled discrete signal $x_0(n)$ can move f_1=1640Hz to the zero position in frequency axis, the f_1 is low-side frequency of refining frequency band, the signal frequency spectrum after shifting is shown in Figure 6.

In the Figure 6(a), the frequency spectrum lines distribution of signal that shifted into lower frequency can be observed. And in the Figure 6(b), although the signal frequency is shifted, the signal frequency spectrum lines distribution and distance are not be changed in band, so the low frequency information can be got accurately.

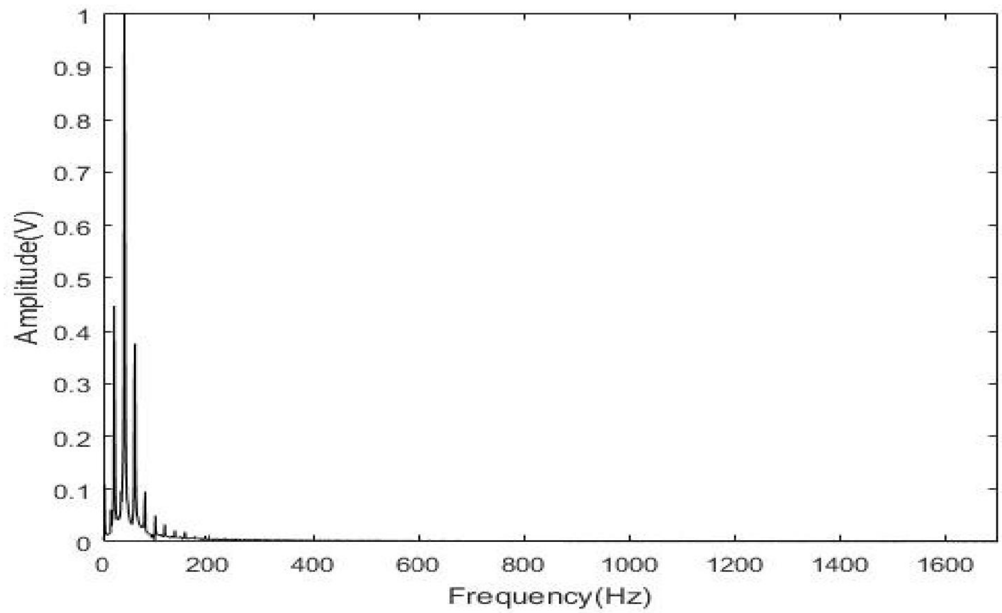

Figure 6(a). The spectrum of signal after shifting frequency

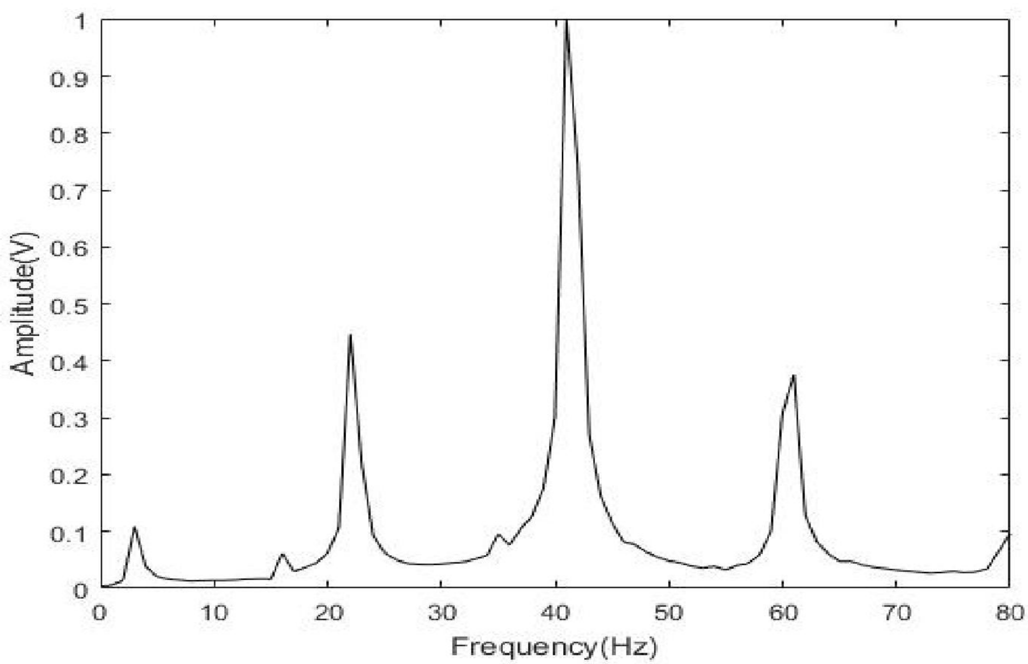

Figure 6(b). The spectrum of in-band signal after shifting frequency

5.3 Low Pass Digital Filter

In order to ensure that resampled signal does not appear aliasing, it is necessary to carry out anti-aliasing filtering. The first step is to calculate the cut-off frequency of low pass filter, due to the original signal is shifted to the lower frequency, we only need to process the signal of 0~80Hz frequency range, so the low pass filter cut-off frequency f_c can be set as 80Hz, then let the frequency shift signal pass low pass filter.

5.4 Resample

In order to obtain higher frequency spectrum resolution, we use the lower sampling frequency to resample, the crucial step is to calculate resampling frequency f'_s. Because direct FFT operation sampling frequency f_s=8192Hz, FFT operation sampling points N=8192, according to the low frequency error is required less than ± 0.03Hz, the spectrum resolution of low frequency is set as 0.03Hz. So the refining times D can be calculated by the $f = 0.03 = f'_s/N = f_s/DN$, $D = 1/0.03$, taking integer of D is 34, and resampling frequency $f'_s = f_s/D = 8192/34$, taking integer of f'_s is 240Hz. Using f'_s=240Hz to resample the low frequency signal, and $x(n)$ is obtained.

5.5 FFT process

Taking sampling points N = 8192 FFT operation to process the discrete signal $x(n)$ that obtained by resampling. The spectrum as shown in Figure 7.

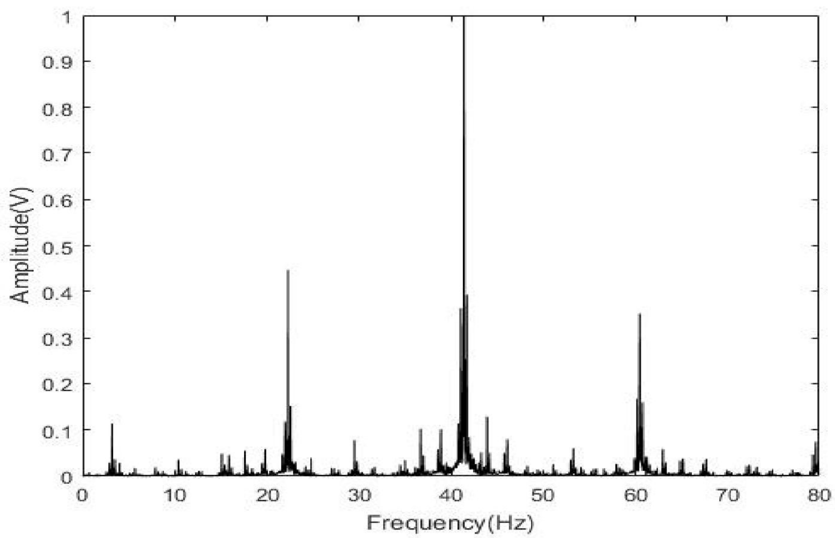

Figure 7. The spectrum of signal after ZFFT processing

Through the above steps, the spectrum resolution of the frequency shift signal is improved D times. In the Figure 7, it is the carrier frequency of frequency shift signal that the highest peak frequency minus 40Hz and plus 1700Hz. the spectrum resolution is 0.03Hz, according to the spectrum resolution of the carrier frequency is required less than 0.1Hz, so the spectrum resolution of ZFFT processing can meet the requirements of carrier frequency resolution. It is the low frequency of frequency shift signal that the highest peak frequency minus second highest peak frequency, which meets the spectrum resolution requirement of the 0.03Hz. These two processes can be achieved by programming in MATLAB, finding the average value of many simulation results, the obtained data are shown in Table 6.

Parameter	Measure value 1	Measure value 2	Measure value 3	Average value	Expecting value	Error	Error require
Carrier frequency/HZ	1701.47	1701.53	1701.45	1701.48	1701.40	+0.08	±0.15
Low frequency/HZ	19.14	19.15	19.12	19.14	19.10	+0.002	±0.03

Table 6. The simulation data of carrier frequency and low frequency

In conclusion, the carrier frequency and low frequency of signal can be got by the detection for the frequency shift signal, and they all meet the requirement of error. The low frequency of signal can be got without shifting the signal spectrum back to the actual position, so the step of frequency shifting is not needed.

6. The Detection of Track Circuit Interference Signal

When the frequency shift signal is transmitted on the track circuit, the frequency shift signal may be interfered by traction current and other environmental. So the received frequency shift signal may be mixed with the interference signal. Therefore, it plays a decisive role for the efficiency and safety of driving that if the track circuit signal can be correctly got under the condition of interference. Through the analysis of track circuit signal frequency spectrum, there is a significant difference between the structure of track circuit shift frequency signal and interference signal[25], we can use the recognition method of spectrum feature to eliminate the interference signal. So it is natural advantage to use frequency domain processing method to distinguish useful signal and harmonic interference signal.

6.1 Analysis of Harmonic Interference Signal

Firstly, finding the interference signal that can enter the frequency shift signal receiving band. The frequency of interference harmonic is integer times of 50Hz, so the interference signals mainly have: (1) It is 1700Hz harmonic that caused by 34 times of

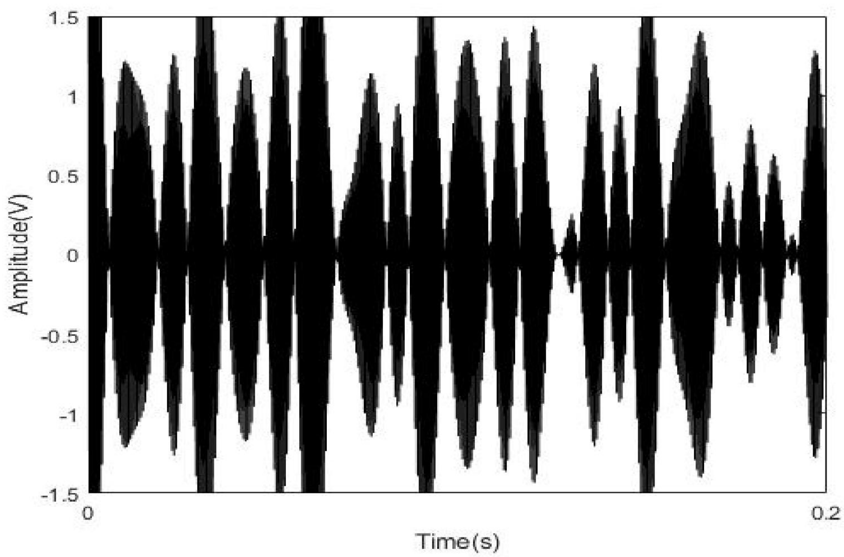

Figure 8(a). The time domain waveform of frequency shift signal after adding interference

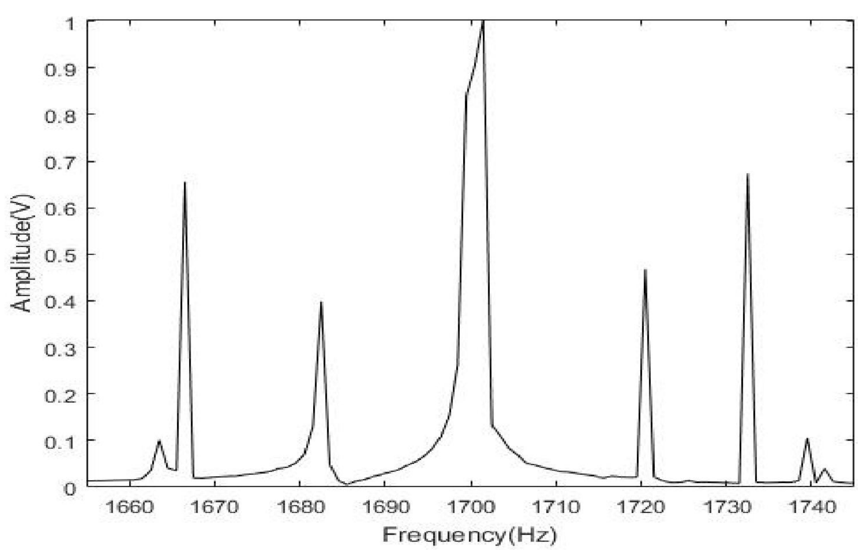

Figure 8(b). The spectrum of frequency shift signal after adding interference

50Hz. (2) Considering the interference caused by the drifting of the power frequency 50Hz, the drifting range is ±1%, the harmonics interference of 1666.5Hz and 1732.5Hz may enter the pass-band, so we set $x = \cos(2\times\pi\times1700\times t) + \cos(2\times\pi\times1666.5\times t) + \cos(2\times\pi\times1732.5\times t)$ as interference signal. Secondly, adding the interference signal into the receiver, only using the traditional FFT algorithm to detect the interference signal, the result is shown in Figure 8.

In Figure 8, we can find that the signal frequency has been changed by the interference, but the spectrum detection cannot discriminate 1700Hz harmonic signal, furthermore, the detection result of other interference signals cannot reach frequency resolution requirements. So it is not reliable to detect the low frequency signal.

6.2 The Detection Process of Track Circuit Interference Signal

The signal that interfered by harmonic will be processed by the refining processing; the result is as shown in Figure 9.

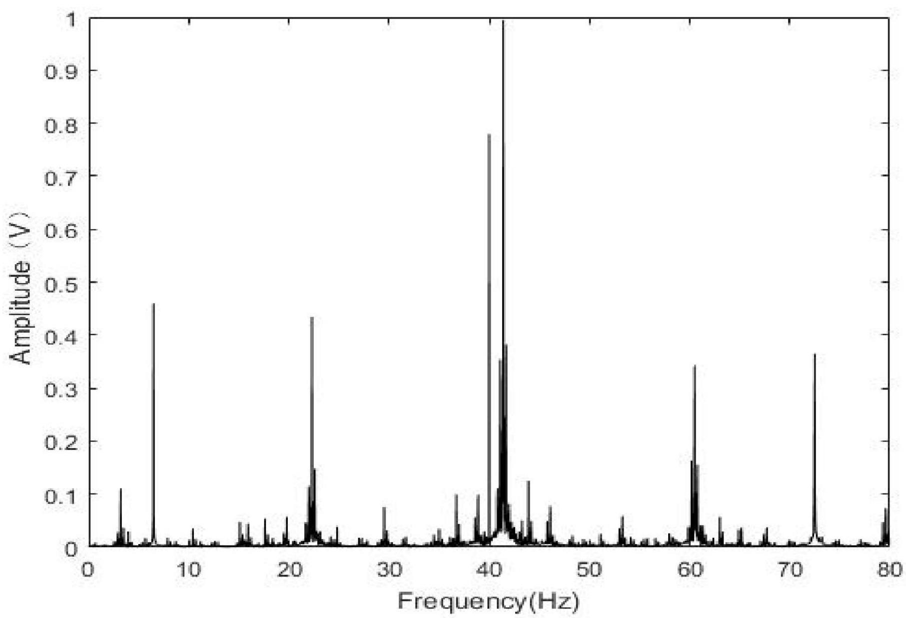

Figure 9. The spectrum refinement process after adding interference

In Fig. 9, we can find that refined spectrum and detect the frequency of the interference signal clearly. We can use the distribution feature of the frequency shift signal spectrum to eliminate the interference signal frequency, and the spectrum range of $f_0 \pm 40$Hz is divided into three regions as shown in Figure 10.

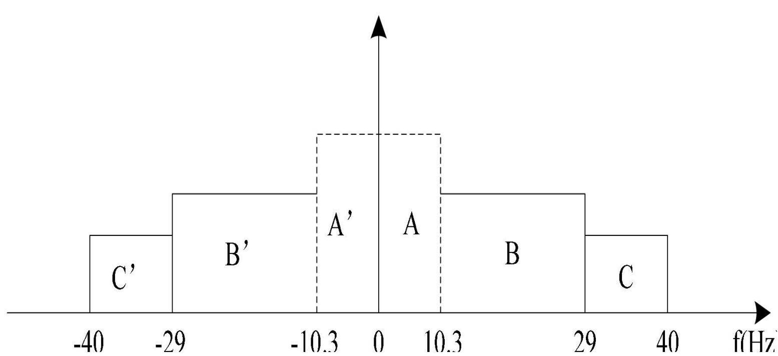

Figure 10. The spectrum segmentation of in-band signal

The distribution characteristics of spectrum as follow:

(1) There is no track circuit frequency information in the A’ and A regions, so the spectrum lines can be eliminated as the harmonic interference in the A and A’ regions.

(2) The B and B’ regions contain the first side frequency of low frequency 10.3 ~ 13.6Hz and the secondary side frequency of low frequency 10.3 ~ 29Hz, and low frequency signal spectrum are symmetric about carrier frequency, if the spectrum are not symmetric, they can be eliminated as interference signal.

(3) The C and C’ regions only contain the secondary side frequency of low frequency 14.7 ~ 19.1Hz, and low frequency signal spectrum are symmetric about carrier frequency, if the spectrum lines are not symmetric, they can be eliminated as interference signal.

According the above three rules to distinguish the obtained spectrum and eliminate the interference signal, which can get the higher reliability signal spectrum and avoid the false low frequency to improve the efficiency and safety of the train.

7. Conclusion

Through analyzing the principle and characteristics of ZFFT algorithm with multiple modulation, combining with characteristics of frequency shift signal and using it in the detection of track circuit signal, which can identify the track circuit signal correctly and remove the harmonic interference signal of in-band effectively to prevent harmonic interference. The simulation results show that the effect of the refining analysis of the frequency shift signal spectrum is obvious, not only improves the resolution of the signal spectrum, but also meets the frequency error requirements. The detection method has the characteristics of high reliability and precision, which can prevent the interference of higher harmonics effectively, and make the detected signals more reliable, so as to ensure the safe operation of the train.

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