

Research on Noise Suppression Technology of "Black Triangle" of Vibroseis Seismic Data

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Abstract. The "black triangle" noise, harmonic interference, and adjacent gun interference in the seismic data collected by the controllable vibrator seriously affect the signal-to-noise ratio of the seismic data. With the emergence of high-efficiency acquisition technology, the "black triangle" noise the impact is getting bigger and bigger. At present, the geological tasks are often accomplished through higher-level seismic data acquisition and indoor fine processing. In order to suppress the "black triangle" noise of controllable seismic data, the effective suppression of the "black triangle" noise has been achieved through the research of high-resolution time-frequency analysis, "black triangle" noise feature extraction, and Wiener filtering. The "black triangle" noise suppression processing of the actual controllable seismic data in the Shun 8 well area of the Tarim Basin has achieved good results. It is of great significance for optimizing the processing effect of the seismic data collected by the controllable seismic source and popularizing the scope of application of the controllable seismic source.

Keywords: Seismic source, seismic data, efficient acquisition technology.

1. Introduction

Seismic exploration is one of the most effective exploration techniques for exploring oil and natural gas. The seismic source is an important part of seismic exploration. Since the 1960s, the controllable seismic source has become one of the important excitation sources for seismic exploration. The impact is much smaller than the explosive source, and it can be used in residential areas, gravel areas, and mountain piedmont areas where drilling is difficult. With the rapid development of controllable seismic source seismic exploration technology, a series of high-efficiency acquisition technologies such as alternate scanning acquisition technology, independent synchronous scanning technology and controllable seismic source high-fidelity seismic exploration technology have emerged.

While the controllable seismic source brings convenience to the field acquisition of seismic data, there are also some problems that need to be solved urgently. Seismic data collected by controllable vibrators have serious characteristics such as abnormal amplitudes in the triangle area, harmonic interference, and false frequency noise, which have a great impact on the quality of the data. It is necessary to study effective and efficient acquisition noise suppression techniques [1]. From the perspective of single shot analysis, the "black triangle" noise, harmonic interference, adjacent shot interference, and fixed noise source interference brought by the controllable seismic source have seriously affected the signal-to-noise ratio of the collected data [2]. Identifying classification and

developing corresponding noise removal methods are the only way to perfect the controllable source technology [3].

Domestic and foreign scholars have conducted a certain degree of research on the noise of controllable seismic sources, and proposed a series of controllable seismic source noise suppression methods, such as fractional frequency domain separation method, pure phase shift filtering, prediction subtraction, deconvolution subtraction method, and harmonics. Interference joint suppression methods, etc. [4-7], these controllable seismic source noise suppression methods have suppressed the "black triangle" noise to a certain extent, but due to the limitations of the theory itself, the effect is not ideal.

In order to effectively suppress the "black triangle" noise interference in the seismic data of the controllable vibrator, this paper proposes the "black triangle" noise suppression technology for the seismic data collected by the controllable vibrator. Resolve time-frequency transform to obtain the characteristic information of the "black triangle" noise and the effective signal, and then use the characteristic difference between the noise and the effective signal to effectively remove the "black triangle" noise in the time-frequency domain, and obtain better than previous methods Noise suppression effect. Through the processing of the seismic data collected by the controllable seismic source in the Shunbei area, a good denoising effect has been achieved, which provides a successful case and method for the noise suppression of the controllable seismic source data.

2. High-resolution time-frequency transform

The actual seismic signal can usually be expressed as a linear combination of a variety of basic waveform signals with different waveform characteristics, such as power frequency interference noise and effective wave signals, surface wave noise and body wave signals in the pre-stack trace. In order to obtain the characteristic information of the seismic data, a Morlet wavelet is selected to construct a wavelet dictionary, which can well represent the characteristic information such as the frequency and amplitude of the seismic data, and then the matching pursuit algorithm is used for time-frequency transformation, thereby decomposing any signal into the most residual error. The sum of well-matched complex time-frequency wavelets. Generally, a Morlet wavelet $m(t)$ centered on μ in the real number domain can be expressed as:

$$m(t) = \exp\left(-\left(\frac{\ln 2}{\pi^2}\right) \frac{\omega_m^2 (t - \mu)^2}{\sigma^2}\right) \cos[\omega_m(t - \mu) + \phi] \quad (1)$$

Where represents the average angular frequency, represents the width of the control waveform, and represents the phase shift. Therefore, a Morlet wavelet can be represented by the above four parameters as. Through matching tracking technology, a seismic trace can be expressed as:

$$f(t) = \sum_{n=0}^{N-1} a_n m_{\gamma_n}(t) + R^{(N)} f \quad (2)$$

Where is the wavelet amplitude of the nth iteration, is the optimal Morlet wavelet generated by the nth iteration, and is the noise of the data. After decomposing a signal into a series of wavelets, the time-frequency amplitude spectrum can be calculated by the following formula:

$$Af(t, \omega) = \sum_{n=0}^{N-1} \frac{\sigma_n}{\|m_{\gamma_n}\|} \left(\sqrt{\frac{\pi}{2 \ln 2}} \frac{\sigma_n}{\omega_n} \right)^{1/2} \times \exp\left[-\left(\frac{\ln 2}{\pi^2}\right) \frac{\omega_n^2 (t - \mu_n)^2}{\sigma_n^2}\right] \times \exp\left[-\left(\frac{\pi^2}{4 \ln 2}\right) \frac{\sigma_n^2 (\omega - \omega_n)^2}{\omega_n^2}\right] \quad (3)$$

Among them, $\omega_n = \omega_{m,n}$ Represents the average frequency of the nth iteration wavelet, $\|m_{\gamma_n}\|$ represents the regularization factor, then:

$$\|m_{\gamma_n}\|^2 = \frac{\pi}{2} \sqrt{\frac{\pi}{2 \ln 2}} \frac{\sigma}{\omega_n} \left(1 + \exp\left[-\frac{\pi^2 \sigma^2}{2 \ln 2}\right] \cos \phi \right) \quad (4)$$

In order to show that the high-resolution time-frequency transform can effectively extract the characteristic information of the signal, short-time Fourier transform and continuous wavelet transform are selected to carry out the time-frequency transform of the same signal. The effect is shown in Figure 1. It can be seen by comparison, The short-time Fourier transform cannot better represent the amplitude information of the signal at 0.25s and 0.85s. Compared with the short-time Fourier transform, the continuous wavelet transform can better represent the amplitude information, but the time resolution and The frequency resolution is low, and the high-resolution time-frequency transform method can clearly distinguish each frequency component in the signal. The resolution is improved compared with the short-time Fourier transform and the continuous wavelet transform.

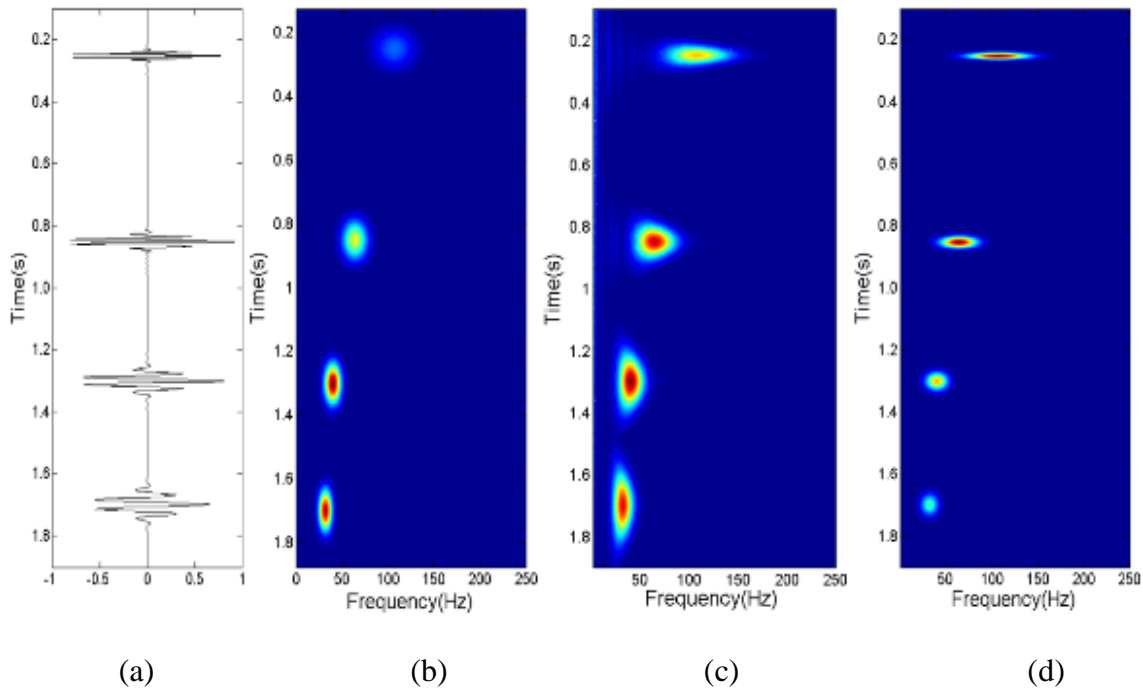


Figure 1. (a) Original input signal; (b) Short-time Fourier transform spectrum; (c) Continuous wavelet transform spectrum; (d) High-resolution time-frequency transform spectrum.

3. Wiener Filter

Wiener filtering is a kind of optimal linear filter, which generates the optimal estimation of the reference signal by linear time-invariant filtering of the observation signal containing noise, so that the mean square error between the optimal estimation and the reference signal is minimized. So as to achieve the extraction of useful signals from the noise. Set the filter output signal as $y(t)$, and its expression is:

$$y(t) = f(t) * x(t) + n(t) \tag{5}$$

Among them, $x(t)$ is the input signal, $f(t)$ is the filter function, and $n(t)$ is the noise. It is required to minimize the error between the output signal and the original signal, that is: $e(t) = x(t) - y(t)$ is the smallest, and the convolution integral form of $y(t)$ is:

$$y(t) = \int_{-\infty}^{+\infty} f(\tau) [x(t - \tau) + n(t - \tau)] d\tau \tag{6}$$

The mean square error (MSE) can be expressed as:

$$E(e^2) = E\{[x(t) - y(t)]^2\} \tag{7}$$

Take $y(t)$ into $E(e^2)$ and obtain the partial derivative:

$$E(e^2) = R_x(0) - 2 \int_{-\infty}^{+\infty} f(\tau) R_{xy} d\tau + \iint_{-\infty}^{\infty} f(\tau) f(r) R_y(\tau - r) d\tau dr \quad (8)$$

Among them, R_x and R_y are the autocorrelation functions of the input signal $x(t)$ and the output signal $y(t)$ respectively, R_{xy} is the cross-correlation function of $x(t)$ and $y(t)$, if the input signal $x(t)$ is not correlated with the noise $n(t)$, then $R_{xy} = R_x$, $R_y = R_x + R_n$. The discrete form of the Wiener-Hopf equation is as follows:

$$R_{xy}(j) = \sum_{i=1}^{N-1} Hopt(i) R_{yy}(j - 1) \quad (9)$$

The formula can be expressed as a matrix form, $R_{xy} = R_{yy} Hopt$, as long as R_{yy} is non-singular, and then get $Hopt = R_{yy}^{-1} R_{xy}$.

4. Controllable vibration source "black triangle" noise suppression technology

In order to ideally suppress the "black triangle" noise in the controllable source seismic data, improve the signal-to-noise ratio of pre-stack data, and provide higher-quality gathers for subsequent pre-stack migration, velocity modeling, and pre-stack inversion, This article proposes the "black triangle" noise suppression technology for controllable source seismic data.

The "black triangle" noise in the seismic data collected by vibroseis is the noise caused by complex near-surface factors, not simple random noise. It is mainly composed of surface waves, surface wave converted waves and surface wave scattered waves, with amplitude Very strong, in a messy and irrelevant state, the apparent speed is unstable, and the aliasing is quite serious. The work areas with different seismic geological conditions and the noise characteristics obtained under different excitation conditions also have great differences. Since the "black triangle" noise is mainly distributed in the developmental position of the surface wave, it will obscure a large part of the body wave information.

According to the regional characteristics of the "black triangle" noise, the background energy information of the effective signal can be obtained through the long-offset seismic traces, and the time-frequency domain data of the short-offset seismic traces and the far-offset seismic traces can be used to obtain the "black triangle". The characteristic difference between the "triangular" noise and the effective signal, and use the difference to construct a Wiener filter, and then the data containing the "black triangle" noise is suppressed by the Wiener filter in the time-frequency domain, and finally through the inverse time-frequency Transform to obtain the time-domain seismic trace after noise suppression.

5. Actual data application

In order to verify that the noise suppression method based on high-resolution time-frequency analysis to extract noise features can effectively improve the signal-to-noise ratio of seismic data collected by controllable seismic sources, the controllable seismic source data collected in the Shun 8 well area on the northern edge of the Taklimakan Desert is selected for processing.

A total of 6 shot points were arranged for the controllable seismic source collection, and 40 geophone lines were laid, each with 270 geophone lines, and the number of coverage was 900 times. The profile data has a high signal-to-noise ratio and resolution, and geological phenomena such as faults and igneous rock intrusions are obvious, which can more truly and clearly reflect the characteristics of the underground geological structure. The types of interference waves in the collected seismic data are complex and diverse, and they are mainly the "black triangle" strong-amplitude surface waves generated by the seismic source. Figure 2 shows the result of noise suppression on the "black triangle" of collected seismic data. From the difference before and after noise removal, it can be seen that this method can better protect effective signals while suppressing noise.

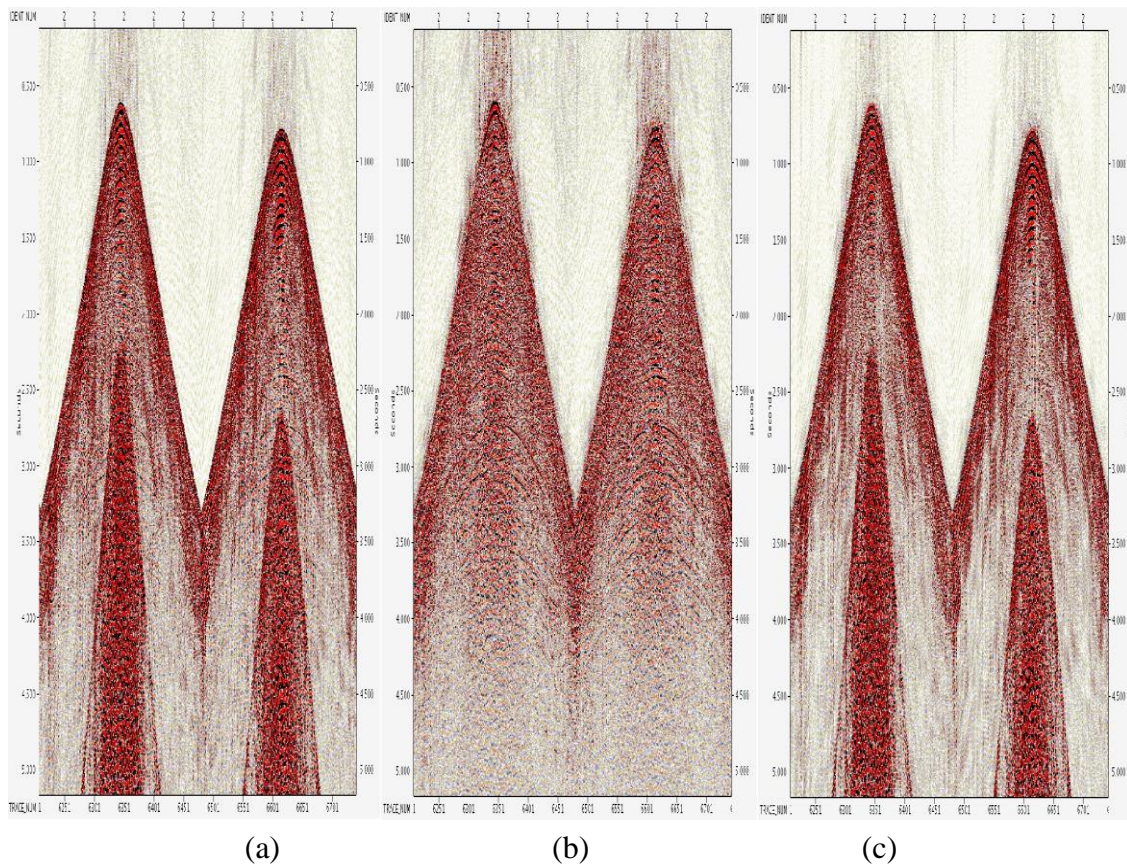


Figure 2. Denoising effect (a) before denoising; (b) after denoising; (c) difference

After suppressing the noise in the "triangular area" of the controllable seismic source, the signal-to-noise ratio of the data has been significantly improved, but the energy of the deep reflection wave is still weak. Therefore, after the noise suppression, the surface consistent amplitude compensation, mixed phase deconvolution, High-precision residual static correction, fine velocity modeling, pre-stack time migration and other processing have significantly improved the resolution of the profile. Compared with the explosive source data, the pre-stack time migration result of this processing has a higher signal-to-noise ratio and resolution High (Figure 3).

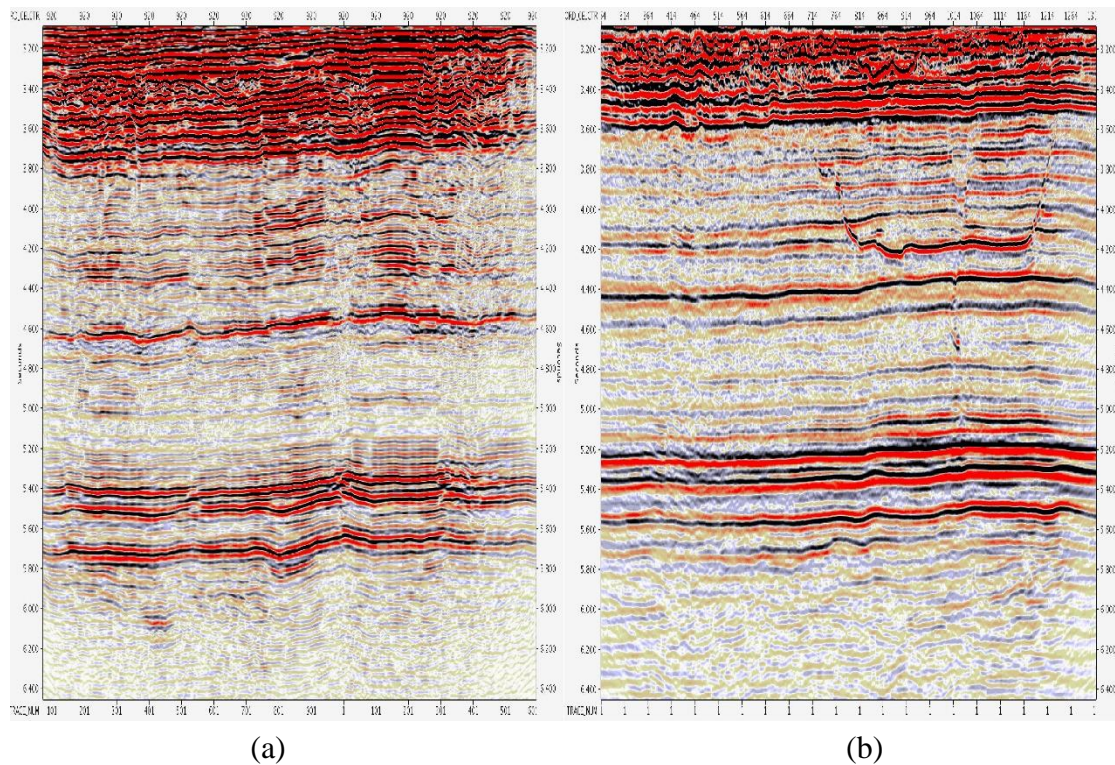


Figure 3. Pre-stack time migration profile (a) controllable seismic source; (b) well shot

6. Conclusion

Aiming at the "black triangle" noise of controllable seismic data, according to the waveform structure characteristics of the effective signal and noise interference, a high-resolution time-frequency analysis method is developed to analyze the characteristics of the "black triangle" noise and effective signal, and then use matched filtering technology. The "black triangle" noise is suppressed to achieve a better denoising effect. The noise suppression technology proposed in this paper is used to suppress the "black triangle" noise and other types of noise from the controllable seismic source data in the Shun 8 well block of the Tarim Basin, and obtain good results, verify the effectiveness of the method, and optimize the controllable seismic source. The processing effect of the collected seismic data and the promotion of the applicable scope of the controllable seismic source are of great significance.

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