Extraction Method of Vibroseis Phase Signal Based on Time-Varying Narrowband Filtering

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Abstract. When the phase travel time value increases continuously, the accuracy of the vibroseis phase signal extraction method will be disturbed. Aiming at this problem, a time-varying narrow-band filtering based vibroseis phase signal extraction method is designed. Calculate the linear sine signal expression formula, build a vibroseis simulation model, in the entire relevant time domain, the scanning signal satisfies the set frequency bandwidth, extract the characteristics of the noise generation mechanism, use the time-varying narrowband filter to scan the global seismic phase, and near-field data As a reference model, set the seismic phase signal extraction mode. Experimental results: The average extraction accuracy of the vibroseis phase signal extraction method in this paper and the other two vibroseis phase signal extraction methods are: 76.798%, 66.359%, and 66.694%, respectively, indicating that the band becomes narrower when fully combined. After filtering technology, the accuracy of the designed vibroseis phase signal extraction method has been improved.

Keywords: Time-Varying narrowband filtering · Vibroseis · Seismic phase signal · Extraction method · Sinusoidal signal · Harmonic interference noise

1 Introduction

While the vibroseis is being applied, the disadvantages of long time-consuming and low construction efficiency for the vibroseis acquisition of a single shot greatly limit the scale of its use [1, 2]. Therefore, in order to improve the collection efficiency of vibrators, many companies have developed a variety of high-efficiency operation methods for vibrators and methods to improve the construction quality of vibrators, and have achieved remarkable results. After decades of technological development, vibroseis has become a widely used mainstream vibrator technology. Vibroseis is a large-scale high-precision seismic exploration equipment that excites seismic wave signals through the principle of reaction. It can continuously generate excitation signal gates with constant amplitude and various frequencies during the working process. Since then, various high-efficiency acquisition technologies for vibrators have doubled their construction efficiency into dozens of times of growth, which is far higher than the construction efficiency of explosive sources. The development of high-efficiency acquisition technology of vibroseis has promoted the

W. Fu and L. Yun (Eds.): ADHIP 2022, LNICST 469, pp. 40–54, 2023.
https://doi.org/10.1007/978-3-031-28867-8_4

rapid expansion of the market scope of vibroseis exploration, and the large-scale application of high-efficiency acquisition technology has in turn promoted the improvement and development of this technology. Compared with traditional explosive sources, the advantage of vibroseis is that the operation process is safe. The excitation signal is controllable, does not have a negative impact on the surrounding natural environment, and the work efficiency is significantly improved. At the same time, the cost of exploration operations is significantly reduced. For technicians, the initial high-efficiency acquisition starts with alternate scanning, which has low technical requirements but can only improve construction efficiency by 50–100% [3].

On the basis of alternate scanning, more efficient vibroseis acquisition technology has been developed. Due to the advantages of high efficiency and low cost, vibroseis have been widely used in many countries. KZ series vibroseis is a hydraulic vibrator with independent intellectual property rights independently developed by China National Petroleum Corporation Orient Geophysical Company. KZ-28 type vibrator is the representative work of this series of vibrators. It has simple overall structure, easy operation, convenient maintenance, low technical support, and enhances the operation ability under harsh conditions. At present, in the Middle East, Africa, Central Asia, America and other countries and regions, based on factors such as safety, environmental protection, operation efficiency, and operation cost. Most oil companies, especially well-known international oil companies, use vibrators to reduce project risks when operating conditions permit. In China, vibroseis have also been widely used in exploration areas such as Northern Xinjiang, Tuha, and Inner Mongolia. It is the first time that the redundant structure design is adopted in the key system, which greatly enhances the reliability of the vibrator. Therefore, the KZ-28 vibroseis has received very good response in exploration applications at home and abroad. In addition, the threshold of alternate scanning technology is low, and the equipment requirements are not high, which is the basic technical reserve of vibroseis acquisition technology. At present, various new high-efficiency acquisition technologies are also developed on the basis of alternate scanning technology. Only by mastering alternate scanning exploration technology can they lay the foundation for the research and construction of other high-efficiency scanning exploration technologies.

2 Extraction Method of Vibroseis Phase Signal Based on Time-Varying Narrowband Filtering

2.1 Building a Vibroseis Simulation Model

The seismic data acquisition method of the controllable source can be substantially divided into the following three categories: conventional acquisition method, high efficiency acquisition method, high fidelity acquisition method. The controllable source is a low energy density excitation source, and the excitation energy needs to be accumulated for a long time [4, 5]. During the signal scan, the continuously changing sinusoidal vibration waveform is known that the frequency increases from low by time when the rass scan is scanned. The controllable source car is in traveling, lifting the vibrator and separated from the ground. Before entering the work, the hydraulic cylinder is lifted up, allowing the weight of the source car through 8 air springs for passive vibration isolation on the top plate and the plate of the vibrator to ensure that the vibrator is tightly coupled to the ground. Usually a linear sinusoidal sweep signal is used, and the linear sinusoidal signal expression formula is:

$$D(\delta) = d_0(\phi) \sin \frac{\delta}{d_0} \times \frac{1}{\delta} \tag{1}$$

In formula (1), d_0 represents the expression of amplitude variation with time, ϕ represents the initial phase, and δ represents the sweep length. However, there are usually obvious harmonic interference and adjacent gun interference in the channel concentration. The efficient acquisition methods of vibroseis mainly include alternate scanning and sliding scanning. Vibroseis forward modeling is an important means and method to study and understand the propagation law of vibroseis seismic waves in complex underground formations. It is of great significance to guide the design of field observation systems and optimize inversion algorithms.

When the vibrator is working, the servo valve opens, and the hydraulic system generates high-pressure hydraulic oil, which alternately enters the upper and lower chambers between the weight and the piston rod, thereby driving the weight to move up and down. The reaction force generated by the hydraulic oil is transmitted to the plate through the piston rod, and the signal generated by the vibrator is transmitted to the ground through the plate, thereby exciting the seismic wave signal. Using the excitation method of the vibrator to simulate, not only can accurately simulate the harmonic interference noise of the vibrator and its secondary interference noise. It can also accurately simulate the characteristic noise produced by various efficient acquisition methods. Then on the basis of formula (1), the frequency expression formula of pseudo-random signal is:

$$\gamma = \sum \frac{(\delta - \eta)^2}{2H} \tag{2}$$

In formula (2), η represents the start scanning frequency, and H represents the end scanning frequency. In order to ensure the stability of the model, four uprights are fixed on the lower plate as guide rods for the spring, and four holes are punched in the corresponding positions of the upper plate. The four guide rods respectively pass through the corresponding holes and cannot affect the vertical vibration of the top plate. The four through holes should be as smooth as possible, and the friction damping should be reduced by applying lubricant on the contact surface with the four guide rods. According to the CRF algorithm, at the same time, the orthogonal body-fitted grid layered coordinate transformation technology is proposed to simulate the complex near-surface structure. It can accurately simulate the secondary disturbance and vibroseis caused by the huge undulating height difference of the dunes [6]. The spring is sleeved on the support rod and fixed on the lower plate and the upper plate, so that the direction of the elastic force acting on the two plates is perpendicular to the upper and lower surfaces of the plates. Therefore, it is ensured that the model can only vibrate in a single degree of freedom in the vertical direction, so as to avoid motion in other directions from affecting the accuracy. Vibroseis seismic exploration is to control the plate by generating a continuous vibration signal through an electronic cabinet, generating a scanning signal whose frequency varies with time, and transmitting the energy of the scanning signal to the ground. When the signal generated by the vibration plate propagates downward, because the scanning signal lasts for a long time, each pulse of the underground reflection layer also lasts for a long time. They are combined into overlapping signals, with complex waveforms aliased together that cannot be distinguished and interpreted.

2.2 Extracting Noise Generation Mechanism Features

When vibroseis exploration is carried out in some special areas, the problem of serious degradation of data quality is sometimes encountered. If the on-site geophysicist wants to improve the acquisition effect by increasing the excitation energy, increasing the scan length is the convenient and easiest way. There are several typical characteristic noises in vibroseis, mainly including harmonic interference noise and surface response noise. Harmonic interference noise can be generated for many reasons, due to the nonlinear nature of the mechanical device and the coupled response distortion of the source substrate-ground coupled system. The seismic wave generated by the vibrator propagates into the ground, and there is inevitably harmonic distortion, which greatly reduces the signal-to-noise ratio of the vibrator data. The scanning excitation signal used in vibroseis exploration is a strictly monotonic long-term scanning signal in mathematical expression. There is a strict definition in the physical concept, conversely, not any signal can be used as a signal excitation in seismic exploration. However, with the gradual improvement of production efficiency, the influence of harmonic interference noise on the effective signal also gradually increases. Therefore, the continuous update of harmonic interference noise suppression technology is promoted.

The methods of suppressing harmonic interference noise can be divided into two methods: adjusting outdoor acquisition parameters and suppressing harmonics indoors. In mathematical concepts, a strictly monotonic signal means that the frequency at any point in the entire signal frequency band is unique, and the same frequency does not appear repeatedly at any time. In the vibroseis construction, if it is up-frequency scanning, it means that the frequency of the scanning signal is strictly increased. If it is a down-sweep, it means that the frequency of the sweep signal is strictly decreasing. Through the analysis of the mechanism of harmonic interference noise, it can be known that the harmonic interference noise is unavoidable. Especially in the efficient acquisition method of vibroseis data, the generation of harmonic interference noise can be reduced by adjusting the field acquisition parameters. But it cannot eliminate harmonic interference noise. Therefore, thorough harmonic interference noise suppression by indoor means has become a necessary choice.

The above mathematical definition determines that in the correlation process, in the entire correlation time domain, after the scanning signal satisfies the set frequency bandwidth, the correlation wavelet has a unique maximum value. That is to say, in the time domain, when the downlink scanning signal reaches the reflection interface at a certain depth, the propagation path of the ray will change. Correlation maxima and strictly decreasing correlation edge perturbations appear in the correlation records. The vibroseis excites a continuous scanning signal, which is roughly divided into linear signal, nonlinear signal and pseudo-random signal according to the nature of the scanning signal. On the basis of the above description, the scanning signal type is obtained, as shown in Fig. 1:

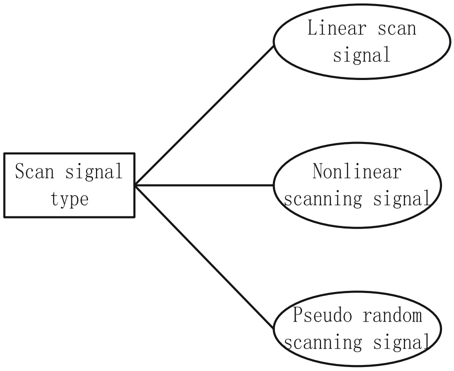

Fig. 1. Schematic diagram of scanning signal tyes

As can be seen from Fig. 1, the types of scanning signals mainly include: linear scanning signals, nonlinear scanning signals, and pseudo-random scanning signals. During vibroseis exploration, due to the influence of various factors, the special noise of vibroseis cannot be avoided. The first type of characteristic noise is generated by the distortion of the mechanical system device or the nonlinearity caused by the seismic plate-ground coupled system. This kind of harmonic noise can be stored by the force signal of the vibration plate, which is called the harmonic noise contained in the force signal, which is the harmonic noise in the narrow sense. In the following text, we call it harmonic interference noise.

The nonlinear scanning signal often sacrifices a certain low-frequency signal-to-noise ratio in exchange for improving the resolution of the geological target. The second type of characteristic noise is due to the coupling difference between the vibrating plate and the surface structure, so that the seismic phase signal stored by the vibrating plate is quite different from the truly propagated vibrator distortion signal. And if the frequency of the vibrator is equal to the natural frequency of the earth, resonances will be generated, which will interfere with the seismic records produced by the vibroseis. That is to say, only on the premise that the linear scanning signal can obtain a better signal-to-noise ratio, it is possible to use the nonlinear scanning signal to further improve the quality of the seismic acquisition data.

This is a typical manifestation of the conflict between signal-to-noise ratio and resolution in seismic exploration work. Such harmonics cannot be stored in the force signal in the vibration plate. Therefore, it is also impossible to use methods such as predictive filtering to separate the shock plate force signal to eliminate the influence of harmonic noise, which is called surface response harmonic noise. If the original excitation is a scan signal with time-invariant amplitude spectrum characteristics, it is easy to adjust by increasing the scan length. However, if the original excitation is a scanning signal with time-varying amplitude spectrum characteristics, it is not easy to adjust by increasing the scanning length. Because increasing the scanning length will lead to the deformation of the signal amplitude spectrum, it is generally necessary to increase the number of vibrators or increase the number of vertical stacking to achieve the purpose of increasing the energy.

2.3 Time-Varying Narrowband Filtering Sweeps Global Seismic Phase

Because the three-phase asynchronous servo motor used in the precision vibrator is limited by the accuracy of the motor servo. Compared with the theoretical value, there is an error between the actual frequency of the source transmitted signal, and the actual transmitted waveform is often difficult to fully satisfy the linear frequency modulation signal. Taking a linear scan signal as an example, when the input of the vibrator control device is a linear scan signal. Due to the distortion of the mechanical system of the vibrator and the distortion of the vibration plate and the earth system, the output signal on the vibration plate of the vibrator is a nonlinear distortion signal [7].

The transmitted frequency often deviates from the theoretical design frequency at certain moments. In order to obtain a more accurate actual transmitted signal, a frequency error model correction method is proposed to complete the correction of the near-field waveform. All nonlinear signals can be extended by Fourier series theory into a superposition of a series of linear signals. Including the frequency equal to the main frequency of the original signal is the fundamental signal. That is, the input linear scanning signal, the frequency equal to twice, three times, and four times the frequency of the original signal is the second harmonic, the third harmonic and the fourth harmonic respectively. We generally call the main frequency more than three times the original signal as high-order harmonics. Force signals containing harmonics include ideal sweep signals and harmonic signals of various orders. Therefore, the vibration signal of harmonic distortion can be expressed by the following equation:

$$\varphi = \sum_{i=1}^{n} \sin \frac{\|\mu + 2\pi(i-1)\|}{\mu_i} \tag{3}$$

In formula (2), μ represents the scanning period, and i represents the n-th harmonic signal. The center frequency of the time-varying narrowband filter is filtered according to the actual frequency sweep curve of the active source. After the sweep frequency signal propagates a certain distance, the delay value of the sweep frequency curve is unknown. Therefore, the premise of filtering the recorded data of the station is that the starting point of the frequency sweep signal needs to be known, that is, the travel time parameter needs to be estimated first. There are many reasons for the nonlinearity of the vibrator mechanism. It mainly includes the nonlinearity of the encoder device, the nonlinearity of the hydraulic system, the nonlinearity of the accumulator, the nonlinearity of the servo valve, the nonlinearity of the accelerometer and the nonlinearity of the coupling between the piston skin and the weight.

In order to detect the first arrival of the vibroseis sweep signal, time-varying narrowband filtering is performed by continuously changing the delay value. The cross-correlation between the filtered far-field station record and the seismic phase signal is used to obtain the maximum amplitude, and the scanning curves of different maximum amplitudes corresponding to different delay values can be obtained. If there is a seismic phase signal, and the frequency corresponds to the passband of the time-varying filter, the maximum amplitude of the cross-correlation obtained after filtering is large. From this, it can be concluded that there is an obvious regularity in the time position of the harmonic interference noise. By cross-correlating the distorted signal expression (2) with the scanning signal expression (3), the excitation signal time using linear upscaling is obtained. The two time intervals of the harmonic interference noise signal are expressed as:

$$R_1 = \frac{(g-1)}{\Delta h} \times Fh_1 \tag{4}$$

$$R_2 = \frac{(g+1)}{g\Delta h} \times Fh_2 \tag{5}$$

In formulas (4) and (5), g represents the phase spectrum of the harmonic signal, F represents the bandwidth of the sweep signal, h_1 represents the first-order harmonic energy, and h_2 represents the second-order harmonic energy. Transform domain interference suppression technology has two research priorities, one is the selection of orthogonal transform, and the other is how to effectively identify and suppress interference components in transform domain, that is, the study of transform domain processing algorithms. Simply put, transform domain processing can be divided into two types: trade-off-based and adaptive-based. If there is no vibroseis sweep frequency signal, the maximum amplitude after cross-correlation is small and unstable.

The peaks appearing in the scanning curve are relatively stable and have regular peaks, which indicate that the source waveform and the station waveforms achieve the best match, so this peak can be used as an estimate of the first arrival. As the name implies, the trade-off-based transform domain processing is that when it is determined that a transform domain coefficient contains interference components, the coefficient is completely set to zero, otherwise the value of the transform domain coefficient is not changed. The adaptive-based transform domain processing uses an adaptive algorithm to minimize the statistical error between the output signal and the expected value.

Since the frequency of the frequency sweep curve of the precise control source is determined at a certain moment, it is possible to perform filtering in a very narrow range near the emission frequency corresponding to that moment. It can suppress the influence of noise to a greater extent and obtain data quality with better signal-to-noise ratio. After correcting the frequency deviation of the active phase signal and estimating the first arrival of the vibroseis sweep frequency signal. It can perform time-varying narrow-band filtering and seismic phase separation for far-field station observation data.

2.4 Set the Seismic Phase Signal Extraction Mode

Use the source approach recording signal to correct the sweep signal. Corresponding to a specific moment, the change of the center frequency of the time-varying narrowband filter is consistent with the frequency of the seismic phase signal. Using the time-varying narrowband filter to filter the near-field signal of the source, we can get 61 different filtering results.

When selecting the frequency range for extracting the seismic phase signal, the frequency response of the stratum in the construction area should be considered first. The frequency response of the stratum is different in different regions and strata. Generally speaking, in the same area, the frequency response of the shallow layer is higher, and the response frequency of the deep layer is lower. If the frequency of the seismic phase signal just falls in the filter frequency band with a certain offset center frequency, the output signal energy value at this moment is the largest. That is, the filtering result with the largest energy corresponds to the actual frequency of the frequency sweep signal, so as to determine the offset of the frequency sweep curve of the source to the theoretical value at a certain moment. This is the principle of frequency correction of the seismic phase signal.

If the geological task is to understand shallow structures, the higher frequency extracted seismic signals should be used. If you want to understand the deep structure, you should use the lower frequency extracted seismic signal. If you want to understand the structure and interrelationship of shallow, middle and deep layers. Then the frequency band for extracting the seismic phase signal should be wider to adapt to the shallow, middle and deep frequency responses. The formation frequency response of a region can be obtained from existing geological data and well log tests.

Through a certain step change time point, the actual frequency sweep curve of one cycle can be obtained. in actual data processing. In order to ensure that the time domain signals corresponding to different frequencies can contain a complete periodic signal, the signal points for intercepting and calculating the energy should have a certain number, and the correction frequency points are sampled at 0.3 s. Finally, the frequencies at other times are obtained by linear interpolation. When determining the frequency range for extracting seismic phase signals, attention should also be paid to the characteristics of the surface structure in the construction area. The thickness of the surface layer in different areas is different, and the absorption of different frequencies is also different. When the surface seismic phase signal passes through the low-velocity zone, it is equivalent to passing through a low-pass filter. The realization of the seismic phase separation extraction technique depends on knowing the starting point of the frequency sweep signal in advance. Here, the starting point of each cycle of the sweep frequency signal is set as the same starting point for all vibrations. Using the near-field data as a reference model, the time-varying narrow-band filtering is performed on the data of a certain far-field station at a certain time. And according to the principle of zero-phase filter to eliminate the phase shift of the filtering result.

Use the filtering result to perform cross-correlation with the near-field source data, take the maximum value of the cross-correlation value, change it to the time value in turn, and obtain the maximum cross-correlation value corresponding to different times. If the inner surface of the construction area is loose and dry, and the low-velocity zone is relatively developed, its absorption of high-frequency components is serious. At this time, the frequency range for extracting the seismic phase signal should be lower. The design of the starting frequency of the vibroseis to extract the seismic phase signal is also a very critical selection parameter. At present, most of the seismic phase signals in the excitation process of the vibroseis are extracted by up-frequency. Therefore, the design of the initial extracted seismic phase signal we discussed is usually about the low-frequency initial seismic phase signal. The attenuation of the surface has a great influence on the surface response noise. The relationship between the surface attenuation and the surface response noise is simulated and tested by using vibroseis Ru sound forward modeling. From this, it is concluded that the vibration record is equal to the result of the convolution of the gun force signal and the reflection coefficient:

$$s = \frac{y \otimes \|t - 1\|^2}{2} \tag{6}$$

In formula (6), y indicates that the former term is the fundamental term, and t denotes that the latter term is the harmonic noise term. On this basis, the average value of the amplitude of each channel in each frequency band is calculated. The calculation formula is as follows:

$$V = \frac{\sigma_{mn}}{\sigma} \sum_{n=1}^{y} \frac{1}{r_{mn}} \tag{7}$$

In formula (7), σ represents the average value of the data amplitude of each track, m represents the amplitude value of the y-th track data, and n represents the number of tracks. When there is a stable seismic phase at a certain time, the corresponding mutual maximum value is stable. And using the superposition principle, the scanning processing results of multiple periodic signals are superimposed to obtain the final seismic phase scanning curve. Due to the randomness of noise and the high repeatability of vibrators, the stacking of multiple scans can effectively compress such random fluctuations and highlight the scan peaks of effective signals. For the scanning curves of multiple periods, if the extreme point corresponding to a certain moment can be obtained at the same time, it means that the seismic phase information at that time exists in the record of the station.

Whether it is up-frequency extraction of seismic phase signal or down-frequency extracted seismic phase signal, in the records obtained by excitation, harmonic interference is inevitable, but the degree of interference is different. The harmonic interference produced by the vibrator in the excitation process cannot be eliminated. But not terrible, we have many ways to cut harmonic interference. Furthermore, we can obtain the arrival time information of the seismic phase through the stable peak of the global sweep curve. The repeatability of the scanning results is good, which also shows that the source excitation signal has good repeatability. And the recorded signal of this station has a higher signal-to-noise ratio.

3 System Test

3.1 Test Preparation

The data processing of the vibroseis swept signal extracted based on the time-varying narrowband filtering technology is mainly realized by the following steps. Moreover, in order to improve the computing efficiency, in the process of study and research, the mixed programming method of Matlab and Visual C ++ is used to realize the whole data processing. As a continuous signal, the data processing method of active source signal is very different from that of natural seismic data. At present, vibroseis data processing includes many tedious steps. In order to better analyze and compare the processing results, and can improve the efficiency of data processing. According to the test requirements, connect the FG-506A signal generator to the SA-PA020 power amplifier. The SA-PA020 type power amplifier is connected to the SA-JZ010 vibration exciter that excites the lower board: the PCI-8603 data acquisition card is inserted into the computer containing the PCI slot.

In the learning process, the independently written programs are integrated into the interactive interface operation based on the Matlab GUI, and the software also adds a small software for random signal analysis in the learning process. At the same time, the terminals are extended, and the AIO and AI 1 interfaces are respectively connected to the output ends of the charge amplifiers connected to the piezoelectric acceleration sensors on the upper and lower plates of the vibrator experimental model. The DAO output interface is connected to the input end of the SA-PA010 power amplifier. In order to reduce the computational complexity of the computer and improve the calculation speed, the original recording is first downsampled from 200 Hz to 100 Hz. Both near-field records and far-field observation station records are down-sampled. Initialize the parameters of the calculation program, including the bandwidth of the time-varying narrowband filter, the sampling rate, etc. The output end of the SA-PA010 power amplifier is connected to the JZ-005 exciter that excites the upper plate. After a series of debugging, all the above devices can work normally, thus completing the deployment of all devices. This filter is used to correct the sweep frequency curve, and the variation law of the sweep frequency curve of the actual transmission is calculated.

3.2 Test Results

In order to verify the effectiveness of the designed vibroseis phase signal extraction method, a comparative experiment is carried out. The wavelet transform-based vibroseis phase signal extraction method and the vibroseis phase signal extraction method based on genetic algorithm are selected, and the experimental comparison is made with the vibroseis phase signal extraction method in this paper. The extraction accuracy of the three methods was tested under different seismic phase travel time conditions. The experimental results are shown in Tables 1, 2, 3, 4 and 5:

Table 1. 500T/s2extraction accuracy of seismic phase travel time (%)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
1	85.614	86.949	93.646
2	86.941	85.341	92.878
3	92.313	87.558	93.646
4	84.556	89.616	95.202
5	87.081	86.334	94.779
6	83.445	87.512	96.546

(*continued*)

Table 1. (*continued*)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
7	83.616	86.992	95.223
8	79.345	85.313	96.314
9	87.405	86.077	95.008
10	79.668	86.963	96.317
11	82.057	87.545	97.548
12	83.664	89.011	96.322
13	85.191	85.162	95.814
14	84.206	86.346	96.071
15	86.772	85.009	95.313

It can be seen from Table 1 that the average extraction accuracy of the vibrator phase signal extraction method in this paper and the other two vibrator phase signal extraction methods are: 95.375%, 84.792%, and 86.782%, respectively.

Table 2. 1000T/s2 extraction accuracy of seismic phase travel time (%)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
1	72.131	75.144	83.160
2	75.418	76.319	82.484
3	76.902	75.208	81.619
4	78.994	76.919	83.445
5	79.613	73.218	82.916
6	72.448	74.067	81.447
7	73.106	75.336	83.699
8	75.431	76.912	82.015
9	78.551	77.433	83.479
10	79.055	75.612	82.164
11	76.228	74.338	82.669

(*continued*)

Table 2. (*continued*)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
12	78.606	77.404	85.314
13	79.449	78.994	86.019
14	75.212	76.303	85.443
15	76.303	77.448	86.494

It can be seen from Table 2 that the average extraction accuracy of the vibrator phase signal extraction method in this paper and the other two vibrator phase signal extraction methods are: 83.491%, 76.496%, and 76.044%, respectively.

Table 3. 1500T/s2 extraction accuracy of seismic phase travel time (%)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
1	62.313	62.599	75.664
2	64.588	66.838	76.913
3	63.942	65.087	75.842
4	64.778	64.919	76.319
5	65.209	66.387	77.448
6	66.311	65.338	76.312
7	65.841	66.205	75.814
8	66.933	67.283	76.901
9	65.177	68.966	75.282
10	66.834	65.311	76.316
11	66.009	63.708	75.255
12	65.846	64.118	76.448
13	67.331	63.009	77.911
14	68.955	62.551	78.306
15	65.744	63.058	79.154

It can be seen from Table 3 that the average extraction accuracy of the vibrator phase signal extraction method in this paper and the other two vibroseis phase signal extraction methods are: 76.659%, 65.721%, and 65.025%, respectively.

Table 4. 2000T/s2 extraction accuracy of seismic phase travel time (%)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
1	62.135	55.142	66.544
2	59.847	53.617	65.911
3	61.006	57.915	64.358
4	59.348	56.912	68.122
5	58.616	61.202	69.313
6	57.311	60.78	67.405
7	57.919	58.334	69.212
8	58.206	59.226	68.513
9	53.363	60.447	69.455
10	58.714	59.161	67.506
11	55.221	58.334	68.224
12	54.301	57.105	68.548
13	53.448	58.494	65.314
14	57.616	56.322	66.008
15	55.142	54.770	67.014

It can be seen from Table 4 that the average extraction accuracy of the vibrator phase signal extraction method in this paper and the other two vibrator phase signal extraction methods are: 67.430%, 57.480%, and 57.851%, respectively.

Table 5. 2500T/s2 extraction accuracy of seismic phase travel time (%)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
1	49.815	55.644	58.647
2	48.633	46.778	57.698
3	49.579	44.322	57.848

(*continued*)

Table 5. (*continued*)

Number of experiments	Extraction method of vibroseis phase signal based on wavelet transform	Extraction method of vibroseis phase signal based on genetic algorithm	The method designed in this paper to extract the phase signal of vibroseis
4	52.116	48.944	58.619
5	47.3361	46.311	59.361
6	49.155	45.915	60.248
7	45.202	48.221	61.225
8	46.113	47.050	62.348
9	44.819	48.099	63.776
10	45.225	47.645	62.551
11	46.915	48.317	63.005
12	45.848	46.955	62.144
13	46.913	46.311	63.948
14	45.649	47.088	62.315
15	46.317	48.912	61.778

It can be seen from Table 5 that the average extraction accuracy of the vibrator phase signal extraction method in this paper and the other two vibrator phase signal extraction methods are: 61.034%, 47.309%, and 47.767%, respectively. Due to the limitation of the research conditions, the secondary disturbance caused by the special noise of vibroseis in the desert area caused by the violent undulating surface and loose sand dunes has not been studied. Because the expression formula of linear sinusoidal signal is calculated in this paper, the simulation model of vibration source is established. In the entire correlation time domain, the scanning signal satisfies the set frequency bandwidth, extracts the characteristics of the noise generating mechanism, and improves the extraction accuracy of the signal.

4 Conclusion

The method for extracting the phase signal of the vibroseis in this paper, and a frequency error correction method is proposed, which can obtain the actual frequency value of the vibroseis transmitted signal to the ground at different times. A comprehensive summary of the two characteristic noises of the seismic phase is carried out, and two characteristic noise suppression methods are developed for the characteristic noises of the two vibroseis. Seismic waves in the range contain rich information about the slow structure of the crust and the upper ground. Waveform observations with larger epicentral distances can constrain deeper structures and provide a basis for the operating mechanism of the earth's interior. A frequency division filtering method of artificial sorting gathers is adopted for the surface response noise, and a combined suppression method and process are proposed. At the same time, the frequency tracked when the time-varying narrowband filter works is more accurate, and the center frequency of the filter can be guaranteed to be within the bandwidth tolerance. In this paper, the expression formula of linear sinusoidal signal is calculated, and the simulation model of vibration source is established. In the entire correlation time domain, the swept signal satisfies the set frequency bandwidth, extracting the characteristics of the noise generating mechanism. The extraction of the seismic phase signal is achieved by scanning the global seismic phase and near-field data using a time-varying narrowband filter as a reference model.

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