Phase scanning method for detuning in thin bed

Fang Li[*], *Siyuan Cao*[*], *Dehua Han*[#], *Jian Yao*[+]
[*]*State Key Laboratory of Petroleum Resource and Prospecting(China University of Petroleum,Beijing);*
[#]*University of Houston;* [+]*Tianjin Branch Company of CNOOC(China) Ltd., Tianjin*

Summary

Thin bed response is one of key concerns in seismic amplitude interpretation, owing to tuning effect that depends on both thickness and offset. We propose a methodology to remove tuning effect in order to obtain true amplitude. Traditional detuning methods can't handle non-zero phase wavelet and can't effectively remove tuning effects of thin layer with thickness above $\lambda/8$ when the tuning effect is most severe. In this study we proposed a new method, called phase scanning, that has potential to solve this problem. The synthetic study shows that our method is effective to any kind of wavelets, noise tolerant, and applicable to a wide range of thickness of the thin-bed.

Introduction

Seismic amplitude is a crucial parameter in seismic data interpretation. True amplitude can render more reliable and valuable interpretation results for risk reduction associate with seismic exploration, especially for thin-bed reservoirs. Tuning effect from the interference of two seismic waves from closely spaced interfaces affects seismic amplitude related to rock and fluid properties. Correcting tuning amplitude is currently a difficult problem.

Different approaches for correcting tuning amplitudes to un-tuning amplitudes have been proposed. Widess (1973) first discussed the tuning effect of thin beds systemically and concluded that at a layer thickness of a quarter of the dominant wavelength of the zero-phase wavelet, maximum amplitude interference occurs. Lin and Phair(1993) proposed a correcting factor as a function of both thickness and offset for quantitative calculation on thin beds bounded by layers that have the same rock properties of top and base layer when using a zero-phase wavelet. Chungt and Lawton(1995) developed analytical expressions for a zero-phase Ricker wavelet and thickness below $\lambda/8$,where λ is the dominant wavelength in the layer . Bakke and Ursin(1998) presented a tuning correction factor for a general seismic wavelet and for offset data. Tuning amplitude factors for common offset of AVO and AVA cases were developed by Ursin and Tygel (2007).

Phase scanning method

The methods mentioned above are inapplicable for non-zero phase wavelets and large thickness of the order of $\lambda/8$. And these situations commonly occur in real seismic data. For thin beds, thickness less than one-eighth of the dominant wavelength, the character of the reflection is that of the time derivative of the incident wavelet (Widess 1973). Based on the differentiation property of the Fourier transform, a time-derivative equates to phase rotation of -90 degree in the frequency domain. As a dynamic parameter of seismic waves, phase changes the waveform in time domain. From this point of view, the response of thin beds within a certain range of thicknesses can be considered as a complex wave where the phase is unlike that of original wavelet.

The phase scanning method we proposed removes the tuning effect of thin beds, and applies to larger thicknesses compared to time-derivative individually. Transmission loss, internal multiples and other mechanisms of energy loss are ignored and dispersion is not included.

Theory

The response of thin beds may be approximated by the two primary P- wave reflections (Bakke and Ursin 1998), giving

$$S(t,y)=R(y)\big(P(t)-P(t-\Delta T)\big) \quad (1)$$

where *t* and *y* denotes time and offset respectively. $R(y)$ is the reflection coefficient and ΔT is the two-way traveltime.

The corresponding frequency expression is then:

$$S(f,y)=R(y)\big(P(f)-e^{-i2\pi f\Delta T}P(f)\big)$$

Simplifying and using $|P(f)|e^{i\theta(f)}$ to denote $P(f)$ results in:

$$S(f,y)=2R(y)|P(f)|\sin(\pi f\Delta T)e^{i(\theta+\alpha)} \quad (2)$$

where, $|P(f)|$ and $\theta(f)$ are the amplitude spectrum and phase spectrum of $p(t)$ respectively. The quantity $\alpha = \pi f \Delta T - 90^0$ is additional phase as an indicator of thin beds. Hence, thin beds add an additional phase α to original phase of wavelet, and extra changes to the true amplitude of thin bed.

The seismic response of thin beds discussed here is composed of two waves with opposite polarity. The response of upper layer of a thin bed can be expressed as:

$$S_{top}(f, y) = R(y)|P(f)|e^{i\theta(f)} \quad (3)$$

The purpose of our work is to extract the top response in equation (3) from the overall response of the thin bed through equation (2). If the seismic response of the base layer is expected, the same method can be adopted for detuning estimation.

The flows for the method applied to a synthetic data set are concluded as follows:

- Generate synthetic data using the reflectivity method in a simple model based on thin bed embedded in two half-spaces, as shown figure 1;
- Apply phase rotation to the data to attain scanning data within a limited range of the phase increments; In general, the behavior of phase rotation can be described as phase adapter without any change to amplitude spectrum. It can be easily obtained by Hilbert transformation in time domain.
- For each trace of new data, perform correlation analysis with the response from the top layer to finding the most fitting phase- increment (α). The result can be written as:

$$2R(y)|P(f)|\sin(\pi f \Delta T)e^{i\theta} \quad (4)$$

- Apply an amplitude correction to obtain the approximate response from the top of thin bed, which is comparable to the exact response in equation (3). From equation (4), there are two terms to be corrected, one of them is a constant 2; the other is the sine term which include thickness and frequency. The latter can be estimated by α . In addition, offset-dependent tuning factor, say cosθ (θ is transmitted angle of thin layer), should be considered (see Lin 1993);

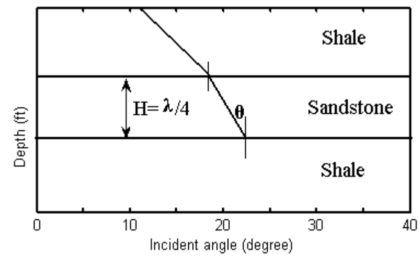

Figure.1 Thin bed model
(incident angle between 0^o and 40^o.)

Lithology	Density (g/cm^3)	Vp (kft/s)	Vs (kft/s)
Shale(top)	2.16	7.19	2.684
Sand	2.11	7.0	2.82
Shale(bottom)	2.16	7.19	2.684

Table 1 Rock and fluid parameters used as an example

Examples

Layer elastic model with two horizontal reflection interfaces (figure 1) is assumed to form a synthetic record, which is to be convoluted with a 30Hz Ricker wavelet of zero-phase or 90^o-phase and maximum amplitude of 1. The parameters of each layer are showed in table 1. Reflection coefficients of the top and base layer are of opposite polarity but have similar magnitudes. Note that the thickness discussed here is the tuning thickness ($\lambda / 4$).

Synthetic datum of the two cases are shown in figure 2 (zero-phase case) and figure 3 (90^o-phase case). Left response (red) of each figure is modeled data with reflectivity method as tuning data, the plot in magenta is the detuning data estimated by our method. The referenced detuning amplitude (blue) is assumed to be the response of the separated top layer in our calculation. The curves in right of the figures are minimum amplitude (because of the negative magnitude of top reflection coefficient.) of three relevant data sets as color drew in synthetic datum. As expected, tuning amplitude is removed greatly, which is very near to the detuning response except for far offset in figure 2 and 3. The results show that there are no requirements needed governing the wavelet so that it is attractive to real seismic data interpretation.

To be more realistic, uncorrelated noise has to be added to synthetic data. Tests for a given noise levels was conducted. Figure 4 shows a test for noise with S/N ratio of 2. It indicates the method can also provide encouraging results in such cases. Because noise added have effect on amplitude of each record time. So the methods based on processing of amplitude will be influenced more or less by noise inevitably. However, waveforms seem not to be insensitive to noise.

Conclusion

The tuning effect, as one of the most serious factors hampering confident lithology and fluid interpretation from seismic data, must be considered, especially for thin-bed interpretation.

Here, we study this problem in terms of the phase and present a new method called phase scanning method. Our method exhibits stability to seismic data with acceptable noise and expands the range of thin bed thickness studied in other papers to above the $\lambda/8$. Also there is no assumption of the wavelet we used, so it is more applicable to real seismic data. However, additional research is required for a more general case of unequal rock properties above and below the thin-bed, i.e. low-contrast layer or high-contrast layer.

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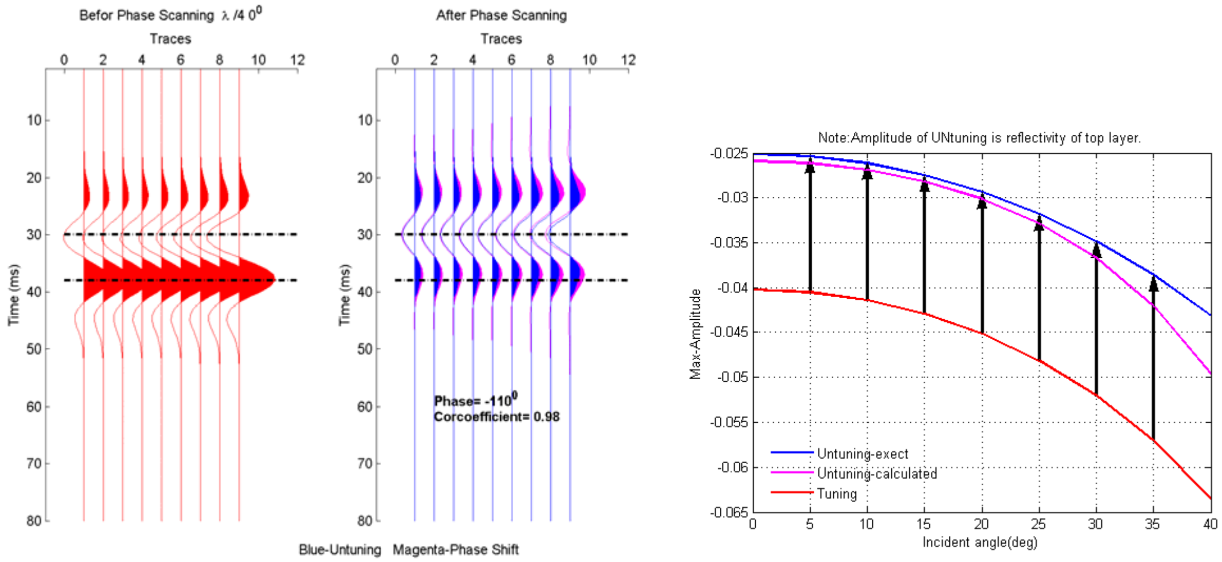

Figure.2 Seismic responses for the case of tuning thickness ($\lambda/4$) and zero-phase Ricker wavelet. Left: tuning response; Middle: Un-tuning response (blue) and calculated data (magenta); Right: minimum amplitude of each trace from corresponding seismic responses (see colors). The most Fitting data is obtained when correlation coefficient equal to 0.98, and addition phase here is -110^{o}.

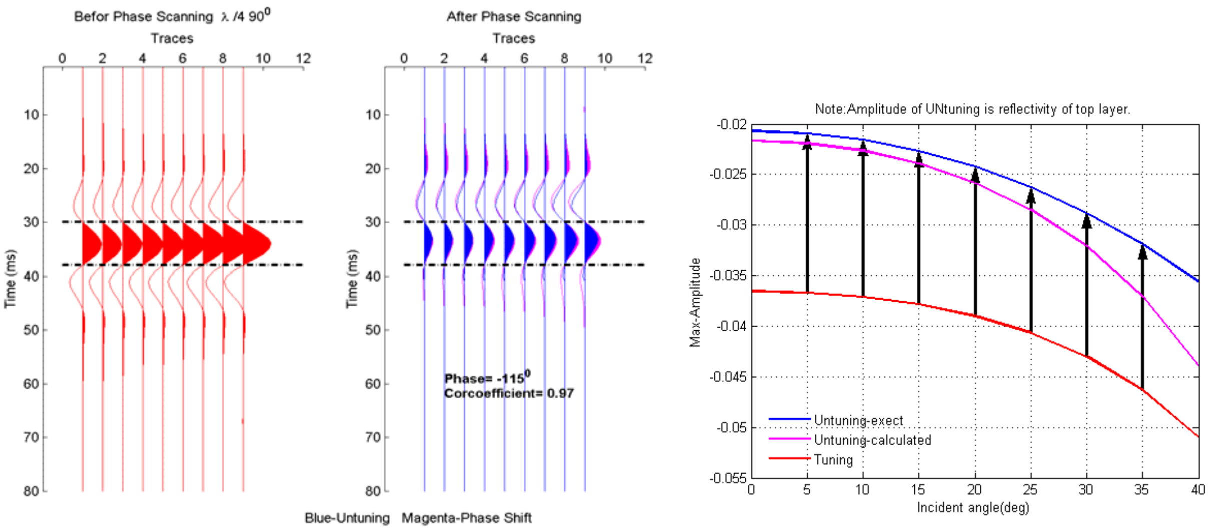

Figure. 3 Seismic responses for the case of tuning thickness ($\lambda / 4$) and 90^0 phase Ricker wavelet. Left: tuning response; Middle: Un-tuning response (blue) and calculated data (magenta); Right: extreme of amplitude of each trace from corresponding seismic responses (see colors). The most Fitting data is obtained when correlation coefficient equal to 0.97, and addition phase here is -115^o.

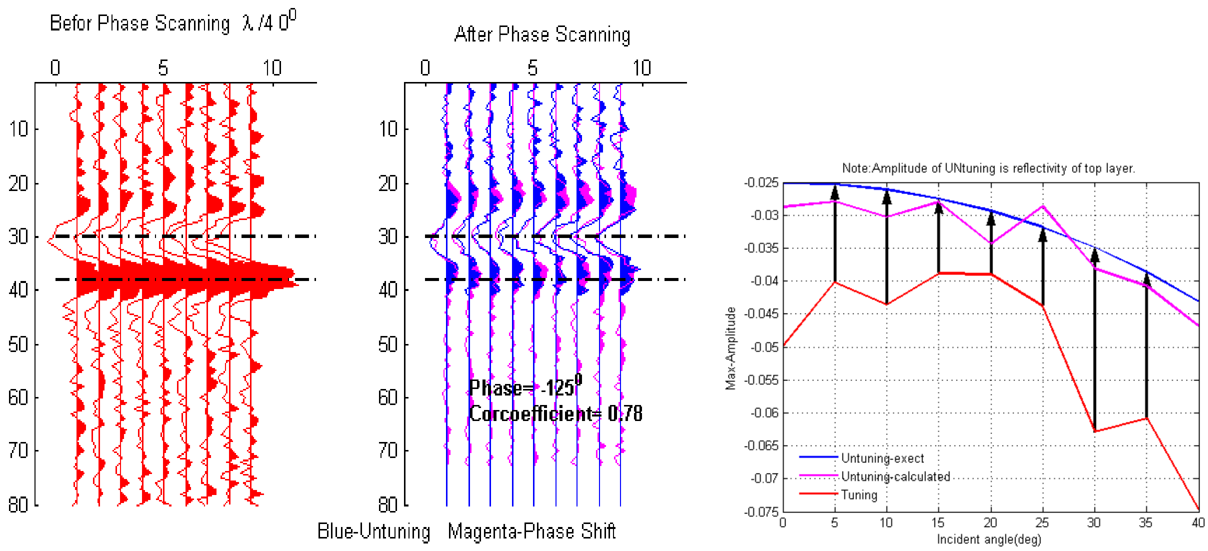

Figure. 4 Seismic responses with random noise of S/N=2 for tuning thickness and zero phase Ricker wavelet. Left: tuning response; Middle: Un-tuning response (blue) and calculated data (magenta); Right: extreme of amplitude of each trace from corresponding seismic responses (see colors). The most Fitting data is obtained when correlation coefficient equal to 0.78, and addition phase here is -125^o.

EDITED REFERENCES

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