Introduction

Restoration of high and low frequencies is an important problem to be solved for VSP data in many applications such as prediction of acoustic impedance beneath the bottom of hole and extrapolation of log data away from the well. An iterative algorithm is proposed for estimation of full spectrum of VSP pulse seismogram. The method is based on an analytical extension of spectrum.

It is known that the prospects of evaluation of geological section from VSP records as well as from surface seismic records are sufficiently restricted by narrow frequency band.

Very low frequencies are not passed by the acquisition system. High frequencies are severely attenuated while propagating through absorptive media. Besides these frequencies are generated in a source with a small weight respectively to dominant frequencies.

There are several reasons for developing and practical application of suggested method:

1. The full wave form of signal is available from downgoing waves.
2. High signal to noise ration is due to absence of surface waves.
3. High frequencies are not absorbed by weathering layer.
4. Spectrum of VSP trace is close to analytic function, because in time domain the trace is limited from the left by the first break point and quickly attenuates to the right.
5. Strong a priori limitations may be available from model produced from log data in the well and applied to starting part of the VSP record.

Method

The applied method of iterative regularization was developed for minimization of convex functional on the set of restrictions [3]. The essential feature of this method is stability to noise. As applied to solution of convolution integral equation $Az = f$ algorithm looks as follows

$$z_{n+1} = \frac{1}{1+\varepsilon_n} P_G\left[z_n - \beta A^*\left(Az_n - f\right)\right] \tag{1}$$

where z_n – approximate solution on n – th step, A – convolution operator, f – known realization of convolution process, P_G – operator of projecting to area of constraints, β, ε_n – parameters of algorithm.

In the discussed problem of estimation of the ideal pulse seismogram from VSP records expression (1) may be written as follows

$$G_{n+1}(\omega) = \frac{1}{1+\varepsilon_n} P_M\left[\left(1 - \beta S_d(\omega)\right)G_n(\omega) + \beta S_u(\omega)\right] \tag{2}$$

where $S_d(\omega)$ – deconvolved downgoing wave, $S_u(\omega)$ – deconvolved seismogram, $G_n(\omega)$ – estimated full spectrum on n–th iteration, P_G -operator of projecting to area of constraints, β – weight of original spectrum, ε_n – regularization parameter.

Real procedure includes application of restrictions to amplitudes in time domain. For example it may be zero values of deconvolved seismogram before first spike of deconvolved VSP trace. In frequency domain this will change every frequency component. The next estimate of pulse seismogram is obtained by inverse Fourier transform of weighted sum of original spectrum and spectrum of seismogram with projection constraints applied. The iterative procedure is repeated until seismogram corresponds to all constraints.

Experimental results

Efficiency of the proposed procedure for restoration of ideal pulse seismogram was tested on model and real VSP data. Acoustic model was derived from sonic density logs for real well. The

wave field was obtained from this model and the dominant frequency of waveform signal was 40 Hz. White noise 2.5% to energy of simulated seismogram was added.
Processing chain included wave separation of original data, optimal deconvolution (regularization parameter – 0.01) and analytical continuation with a priori constraints derived from model. It was assumed that the uncertainty of model is 20%.
As it may be seen on Fig.1(a, b) the main part of energy in deconvolved traces is between 6 and 125 Hz and spectrum of deconvolved trace differs from spectrum of ideal spike (0-250 Hz) seismogram on Fig.1(c) after 100 Hz.
Continued spectrum on Fig. 1(d) covers the whole interval (0-250 Hz) though it is not entirely similar to ideal spike seismogram on Fig. 1(c).

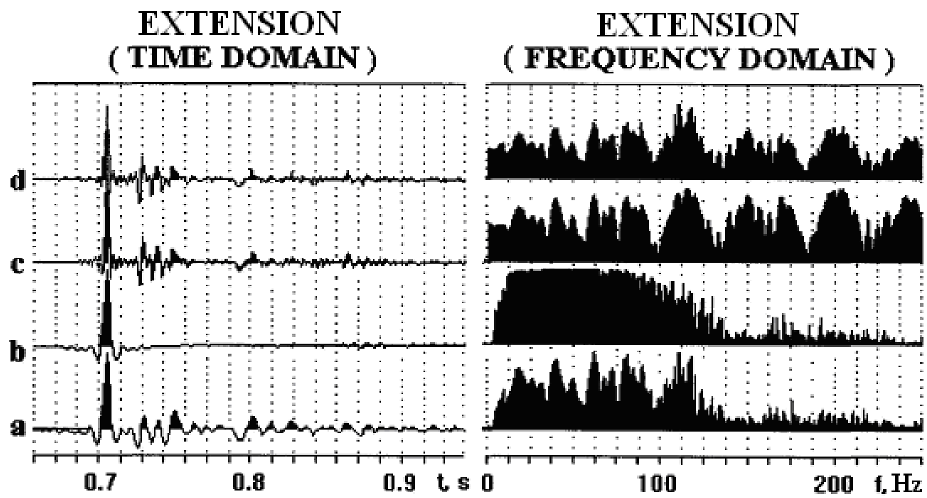

Fig. 1. Analytical extension of spectrum for one simulated trace in time and frequency domains (a – simulated trace after deconvolution, b– downgoing wave after deconvolution, c – trace after continuation, d–simulated pulse seismogram (0-250 Hz).

The whole seismogram with spectrum extension on Fig. 2 is highly resolved in comparison with deconvolved seismogram.

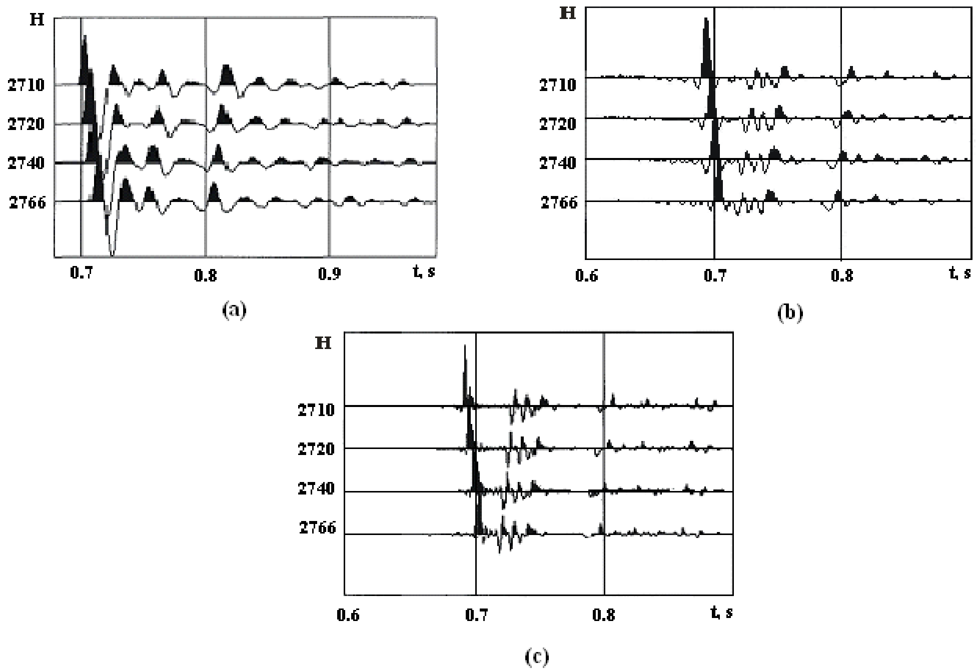

Fig. 2. (a) – model data + 2.5% white noise, (b) – deconvolved signals, (c) – signals after analytical extension.

It is also researched the method convergence on the assumption of time limitation of the signal when

$$\beta = \beta(\omega) = \begin{cases} 1, \omega \in [\omega_1, \omega_2] \\ 0, \omega \in [\omega_1, \omega_2] \end{cases}.$$

The resolution ratio of the method is shown to be weakened in time. However the algorithm is characterized by weak reflections resolution close to first break wavelet (Fig.3).

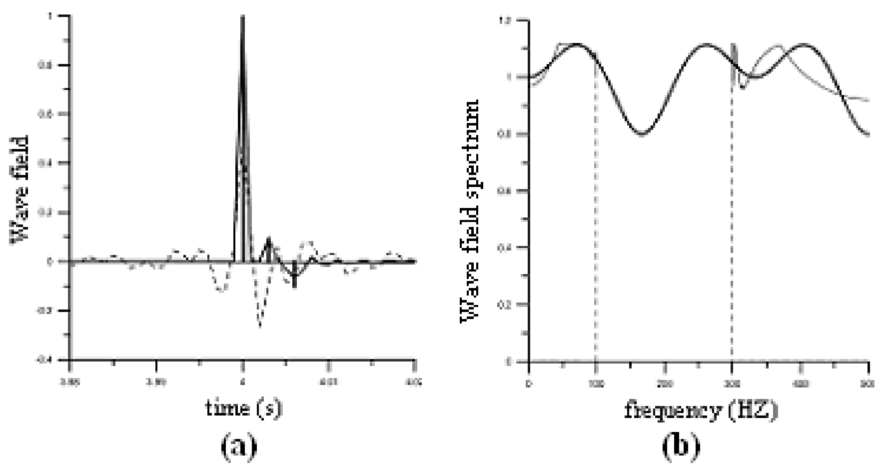

Fig. 3. Wave field (a) and its frequency spectrum (b) for three impulses on the assumption of zero delay in time (bold line – reference wave field (wave field spectrum), dot line – initial wave field (wave field spectrum), solid line – wave field (wave field spectrum) after 1.000.000 iteration).

Conclusions

1. Shown results confirm an opportunity for spectrum expansion of one VSP trace by using of analytical spectrum extension up to 250 Hz in the presence of a priori restrictions from LOG and 2.5% noise level. These results compete with optimal deconvolution results and accruals with observation's densities about 6 tracks per meter without using an a priori restrictions from the LOG .
2. Without a priori restrictions from LOG using of iterative algorithm of analytical spectrum extension allows to restore about 70 % energy of unknown part of spectrum from frequency interval 100-300 Hz up to 0-500 Hz on the distance up to 10 ms. It gives a chance to evaluate close reflections in area usually overlap by secondary extremum of deconvolved downgoing wave.
3. Low frequencies (before zero) are restored better then high frequencies.

References

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3. Bakushinsky A.B. and Goncharsky A.V. 1989. Incorrect problems. Numerical methods and applications. Moscow State University. Moscow.