P228 3D NEAR WELL BORE GAUSSIAN BEAMS IMAGING BY MEANS OF 1D 3C SINGLE-SHOT DATA

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Abstract

Intelligent well completion (Tubel and Hopmann, 1996, Mjaaland et al., 2000) is very promising opportunity of a continuous monitoring of the near well bore formations from the well in order to follow gas-oil contact movement during exploration. But for the very beginning one should recover fine near well bore geological structure. The specific of acquisition system used as a component of intelligent well completion is necessity to deal with 1D 3C acquisition system with very poor source distribution that does not provide a possibility to have any essential overlapping. This causes some troubles in application of common processing procedures like pre- and poststack migration. Another trouble is necessity to recover 3D structure by means of 1D observation. The only reasonable way here seems to extract 3D near well bore structure from 3C data. In order to do that the Gaussian beams approach developed in Goldin et al. (2000) is proposed and tested on some synthetic examples.

Statement of the problem and description of the imaging procedure

Below the main attention will be paid on recovery of 3D distribution of some singularities in the near well bore vicinity. As singularities let us treat scatterers/diffractors, that is small isolated intrusions or some singular points (edges and vertices) onto regular interfaces. The reason to deal with this kind of objects is a possibility to compose more realistic singular objects – faults, cracks, edges and son on – as a set of point scattrers/diffractors. So, below scattered waves will be dealt with only. Next, seismic source placed within fluid filled borehole generates a lot of waves – P- and S-waves that propagates within the medium and tube wave that stays to be concentrated in the very close (less than dominant wavelength) vicinity of the well. So, below scattering of P- and S-waves only will be taken into account. This leads to a possibility to approximate a seismic source placed within fluid filled borehole as some seismic dipole radiating within homogeneous (at least before scattering) elastic medium (Lee and Balch, 1982).

The acquisition system will be dealt with consists of the single seismic source (dipole) at the origin and 3C geophones being spaced with uniform step along x_2-axis within interval $(-L, L)$. Let us introduce the plane π that contains x_2-axis and possesses angle φ with x_3-axis and define straight line (focusing line) $x_2 = x_{2f}$ in this plane. For this focusing line there are two families of rays: the first connects the source with current points on focusing line while the second connects the same current point on the focusing line with some specific point x_{02} ('initial' point) from the acquisition system (see Fig.1). With fixed angle φ the first family of rays is parameterized by the position of the focusing line x_{2f} and "depth" x'_{3f} of the current point along this line, while for the second family of rays one should specify the 'initial' point $(0, x_{02}, 0)$ as well. The choice for these rays to be P- or S-rays is in our hands and depends on the type of the seismic dipole and its disposition with respect to geophones position. It should be stressed, that we do not claim these rays belong to π - plane, they can be totally 3D. We claim that focusing line belongs to this plane

For each fixed angle φ let us treat 3C single shot data $\vec{u}_0(x_2, t)$ as given in the plane being orthogonal to the plane π and introduce 3D Gaussian beam concentrated in the vicinity of the ray that connects initial point $(0, x_{02}, 0)$ with current point on focusing line. The type of this beam is defined by the choice of rays forming mentioned above second family, but in consequence we will deal with second family made of P-rays, so we will deal with P-wave Gaussian beams. Now, similar to 2D situation (Goldin et al. 2000), let us compute "elementary selective image":

$$\Phi\left(x_{02}, x_{2f}, x'_{3f}; \varphi\right) = \left| \int_{\omega_1}^{\omega_2} \exp\left\{-i\omega\, t(x_{02}, x_{2f}, x'_{3f})\right\} d\omega \int_{-L}^{L} \vec{u}_0(x_2; \omega) \cdot \vec{\sigma}^{(gb)}\left(x_2, \omega; x_{02}, x_{2f}, x'_{3f}, \varphi\right) dx_2 \right|$$

Here $t\left(x_{02}, x_{2f}, x'_{3f}\right)$ is travel-time for specific wave that propagates from the source to some current point $\left(x_{2f}, x'_{3f}\right)$ in π-plane and next to the initial point $\left(0, x_{02}, 0\right)$. In particular, $t\left(x_{02}, x_{2f}, x'_{3f}\right) = \tau_P(x_{2f}, x'_{3f}) + \tau_P(x_{2f}, x'_{3f}, x_{02})$ if one is going to deal with PP-scattering. Stress vector $\vec{\sigma}^{(gb)}\left(x_2, \omega; x_{02}, x_{2f}, x'_{3f}, \varphi\right)$ for the specific Gaussian beam is computed as being applied to the plane orthogonal to π-plane. This elementary selective image is nothing else, but backward propagation of data along specific 3D Gaussian beam. The main feature of the Gaussian beam is its exponential decay out of $\omega^{-1/2}$- vicinity of the chosen ray, so described above elementary selective image should possess local minima with respect to the depth x'_{3f} if there is some scatterer that produces scattered wave of the chosen type. Intensity of these local minima is proportional to amplitudes of respective scattered waves. Now one can vary focusing line position and fill some area of π-plane with elementary selective images and, next, rotate π-plane in order to get 3D selective image of the well bore vicinity. One can easy avoid imaging of layered regular interfaces by choice of non-symmetry disposition of x_{2f} and x_{02}.

Numerical experiments

In order to test proposed procedure of Gaussian beams 3D imaging the model presented on the Fig.2 was chosen – homogeneous elastic medium ($V_p = 2873$ m/sec, $V_s = 1639$ m/sec, $\rho = 2083\,\text{kg/m}^3$) with two sets of scatterers placed along two vertical lines being on opposite sides with respect to well bore (x_2-axis). Distance from the source to both of this plane is taken 10m, the distance from scatterers lines to well bore is equal to 10m, the scatterers are spaced along vertical lines with step of 5m starting from 15m. To synthesize scattered waves under Born's approximation Ricker's impulse of 500Hz is used as a source function. Seismic source is taken as a seismic dipole at the origin with $M_{ij} = \delta_{i1}\delta_{j1} + \delta_{i2}\delta_{j2}$. As is proved in Lee and Balch (1982) in far zone it generates the same wave field as volumetric source placed within fluid filled well bore. For the chosen elastic parameters this source in far zone possesses directional diagram presented on the Fig.3. In order to get spatial distribution one should rotate this diagram around vertical axis (x_3 -axis on previous figures).

As one can see, there are two overlapped areas with dominant P - and S - wave amplitude. So, it seems to be reasonable to deal with incident P-wave for space angle around vertical axis and with incident S-wave for space angles with this axis more than $\frac{\pi}{6}$. As one can see after angle $\frac{5\pi}{12}$ there is blind area and one has no possibility to recover something there. So, in order to get 3D Gaussian beam image of the near well bore vicinity two types of travel-times in the formula for selective images should be used – for PP-scattering near vertical direction and for SP-scattering out of $\frac{\pi}{6}$ spatial angle. In order to compute selective images in these areas we should compute selective images for P-wave Gaussian beams with PP or SP travel-times. In order to provide brightness of the image that does not depend on the geometry of the scatterers/source mutual disposition we applied normalization of the image in order to take into account directional diagram of the source and geometrical spreading. The Fig.4 presents two slices of 3D Gaussian beam image: slice for $x_2 = -10m$ (a) and slice for $x_2 = 10m$ (b). One can see, that all scatterers are on the proper positions and possess the same brightness because of renormalization of the image. The very important feature of these images is absence of false images produced by PS- and SS-waves. The reason is that we use P-wave Gaussian beams being 'almost' orthogonal to S-wave in input data.

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References

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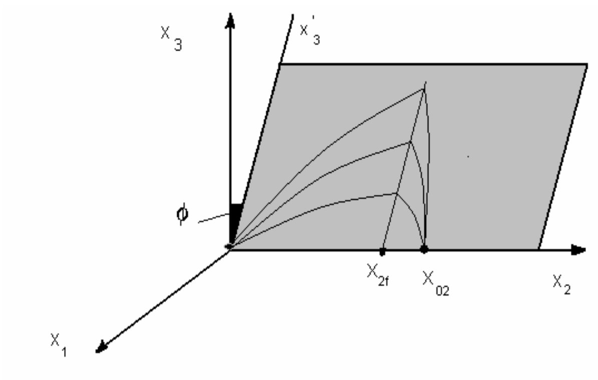


Fig.1. Geometry of the 3D Gaussian beams imaging.

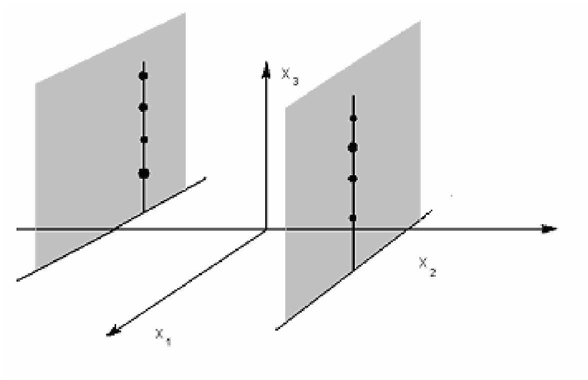


Fig.2. Spatial distribution of scatterers in the well bore vicinity

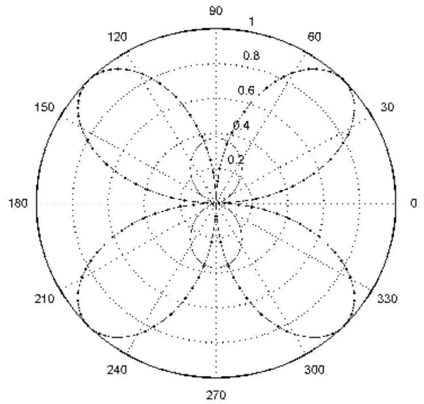
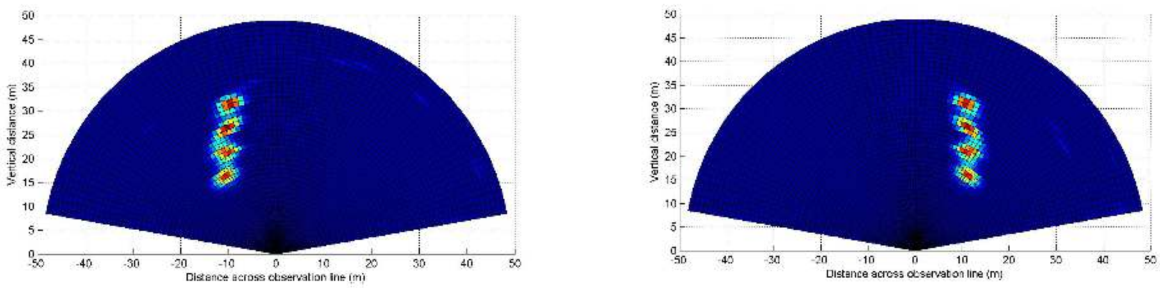


Fig.3. Directional diagram of the used seismic source: solid line – P-wave amplitude, dotted line – S-wave amplitude.



a) b)

Fig.4. Two slices of 3D Gaussian beam imaging a) $x_2 = -10m$; b) $x_2 = 10m$.