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Acousto-electric well logging by eccentric source and extraction of shear wave*

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The nonaxisymmetric acousto-electric field excited by an eccentric acoustic source in the borehole based on Pride seismoelectric theory is considered. It is shown that the acoustic field inside the borehole, converted electric and magnetic fields and coupled fields outside the borehole are composed of an infinitude of multipole fields with different orders. The numerical results show that both the electromagnetic waves and the seismoelectric field in the borehole, and the three components of both electric field and magnetic field can be detected. Measurements on the borehole axis will be of advantage to determining shear velocity information. The components of the symmetric and nonsymmetric acoustic and electromagnetic fields can be strengthened or weakened by adding or subtracting the two full waveforms logged in some azimuths. It may be a new method of directly measuring the shear wave velocity by using the borehole seismoelectric effect.

Keywords: porous media, seismoelectric, well logging, acoustic source
PACC: 4320, 9130, 0350D

1. Introduction

The acoustic waves in solids have attracted many scientists' attention[1−4] due to their important applications in various technical and engineering processes. The study of wave propagation in a fluid-saturated porous medium is of considerable interest in acoustics and geophysics.[5−8] One of the major findings of Biot's theory[9−10] is that there exists a compressional slow wave in a fluid-saturated porous medium. The first clear experimental observation of this slow wave was reported by Plona.[11] Biot[12] predicted the slow waves should have an important bearing on electrokinetic effect. This predication has been quantitatively confirmed by Pride *et al*[13] and Hu.[14] Elastic waves propagating in fluid-saturated porous media can generate a movement of the ions in the pore fluid, and such a movement induces an electromagnetic (EM) field.[15] Pride[16] derived the governing equations for the coupled acoustics and electromagnetic waves in fluid-saturated porous media. Pride and Haartsen[17] analysed the basic properties of seismoelectric waves. In order to detect the acoustoelectric signal effectively, Haartsen and Pride[18] suggested measuring the vertical electroseismic profile. Mikhailov *et al*[19] measured and analysed the electric field converted from low frequency Stoneley waves in a borehole. Seismoelectric effect is also called acoustoelectric effect in acoustical logging frequencies (kHz). Acoustoelectric well logging method has been proposed to detect deep target formation. Zhu *et al*[20] conducted laboratory experiments in model wells. Acousto-electric well logging methods based on the excitation and reception of axisymmetric wave phenomena in a fluid-filled borehole have been investigated.[14,20−23]

In the present paper we consider the nonaxisymmetric acousto-electric field excited by an eccentric acoustic source. We theoretically formulate and numerically simulate both axisymmetric and nonaxially symmetric waves in a fluid-filled borehole. The full waveforms of acoustic waves and electromagnetic waves in the time domain propagation in the borehole are analysed and simulated.

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2. Acoustic field and electromagnetic field in the borehole fluid

Acoustic field. The displacement potential associated with an eccentric source[24] located at $(r_0, 0, 0)$ is given by

$$\Phi_0(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma\epsilon_n K_n(f)\cos(n\theta), \tag{1}$$

where $\gamma = V_0(\omega)I_n(\eta_{\rm f}r_0)$, $f = \eta_{\rm f}r$, $r > r_0$ and ϵ_n is Neumann's factor ($\epsilon_n = 1$ for $n = 0$; $\epsilon_n = 2$ otherwise), $V_0(\omega)$ is the source spectrum, and $\eta_{\rm f}^2 = k_z^2 - \omega^2/v_{\rm f}^2$ is the radial wavenumber with respect to the acoustic velocity of borehole fluid $v_{\rm f}$. K_n is the nth-order modified Bessel function of the second kind. For $r < r_0$, we interchange r and r_0 in Eq.(1). The total acoustic field inside the borehole is given by

$$\Phi(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma[A_nI_n(f)+\epsilon_nK_n(f)]\times\cos(n\theta), \tag{2}$$

where A_n is the reflection coefficient. The radial component of the displacement field is given by $\partial\Phi/\partial r$ and borehole fluid pressure $P(r,\theta,k_z,\omega)$ is given by $\rho\omega^2\Phi$. $\rho_{\rm f}$ is fluid density.

Electromagnetic field. In cylindrical coordinate system(r,θ,z), it is convenient to take the z-components of vectors $\boldsymbol{E}$ and $\boldsymbol{H}$, and they satisfy the Helmholtz-type wave equations without an electric current source,[25]

$$\nabla^2E_z-k_{\rm e}^2E_z=0, \tag{3}$$

$$\nabla^2H_z-k_{\rm e}^2H_z=0, \tag{4}$$

where $k_{\rm e}^2 = \omega^2\mu\widetilde{\varepsilon_{\rm f}}$, $\widetilde{\varepsilon_{\rm f}} = \varepsilon_{\rm f}(1+{\rm i}\sigma_{\rm f}/\omega\varepsilon_{\rm f})$, $\varepsilon_{\rm f}$ is the borehole fluid's electrical permittivity, $\sigma_{\rm f}$ is the borehole fluid's electrical conductivity, μ is the magnetic permeability, and ${\rm i} = \sqrt{-1}$. Considering the radiation conditions, which prescribe that the reflected electromagnetic field should be finite on the axis of the borehole, we can take the solutions for E_z and H_z, respectively, as

$$E_z(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma A_n^{\rm E}(k_z,\omega)I_n(\chi)\cos(n\theta), \tag{5}$$

$$H_z(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma A_n^{\rm H}(k_z,\omega)I_n(\chi)\sin(n\theta), \tag{6}$$

where $\chi = \eta_{\rm e}r$, $\eta_{\rm e}^2 = k_z^2 - k_{\rm e}^2$. $A_n^{\rm E}$ and $A_n^{\rm H}$ are the reflection coefficients. Transverse field components are obtained from Maxwell's equations,

$$E_\theta(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma\Big\{A_n^{\rm E}\frac{{\rm i}k_z}{\eta_{\rm e}^2}\frac{n}{r}I_n(\chi)+A_n^{\rm H}\frac{{\rm i}\omega\mu}{\eta_{\rm e}^2}\times\Big[\frac{n}{r}I_n(\chi)+\eta_{\rm e}I_{n+1}(\chi)\Big]\Big\}\sin(n\theta), \tag{7}$$

$$E_r(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma\Big\{A_n^{\rm E}\frac{{\rm i}k_z}{-\eta_{\rm e}^2}\Big[\frac{n}{r}I_n(\chi)+\eta_{\rm e}I_{n+1}(\chi)\Big]+A_n^{\rm H}\frac{{\rm i}\omega\mu}{-\eta_{\rm e}^2}\frac{n}{r}I_n(\chi)\Big\}\cos(n\theta), \tag{8}$$

$$H_r(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma\Big\{A_n^{\rm H}\frac{{\rm i}k_z}{-\eta_{\rm e}^2}\Big[\frac{n}{r}I_n(\chi)+\eta_{\rm e}I_{n+1}(\chi)\Big]+A_n^{\rm E}\frac{{\rm i}\omega\widetilde{\varepsilon_{\rm f}}}{-\eta_{\rm e}^2}\frac{n}{r}I_n(\chi)\Big\}\sin(n\theta), \tag{9}$$

$$H_\theta(r,\theta,k_z,\omega)=\sum_{n=0}^{\infty}\gamma\Big\{A_n^{\rm H}\frac{{\rm i}k_z}{-\eta_{\rm e}^2}\frac{n}{r}I_n(\chi)+A_n^{\rm E}\frac{{\rm i}\omega\widetilde{\varepsilon_{\rm f}}}{-\eta_{\rm e}^2}\times\Big[\frac{n}{r}I_n(\chi)+\eta_{\rm e}I_{n+1}(\chi)\Big]\Big\}\cos(n\theta). \tag{10}$$

Reflected electromagnetic field inside the borehole in the space–time domain is given by

$$\Pi(r,\theta,z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Pi(r,\theta,k_z,\omega)\times\exp[{\rm i}(k_zz-\omega t)]{\rm d}k_z{\rm d}\omega, \tag{11}$$

where we use $\Pi(r,\theta,k_z,\omega)$ to denote any component of electric or magnetic field given by Eqs.(5–10).

3. Seismoelectric waves in the porous formation

According to Pride's theory,[16,17] without the applied force and electric current sources existing, we may write the equations for the coupled electromagnetic and acoustics in fluid saturated porous media as follows:

$$\begin{aligned}
&\nabla\cdot\tau=-{\rm i}\omega(\rho\dot{\boldsymbol{u}}+\rho_{\rm f}\dot{\boldsymbol{w}}),\\
&\nabla\times\boldsymbol{E}={\rm i}\omega\boldsymbol{B},\\
&\nabla\times\boldsymbol{H}=-{\rm i}\omega\boldsymbol{D}+\boldsymbol{J},\\
&\dot{\boldsymbol{w}}=L(\omega)\boldsymbol{E}+(-\nabla P+\omega^2\rho_{\rm f}\boldsymbol{u})k(\omega)/\eta,\\
&\boldsymbol{J}=\sigma(\omega)\boldsymbol{E}+L(\omega)(-\nabla P+\omega^2\rho_{\rm f}\boldsymbol{u}),\\
&\tau=(H-2G_{\rm b})(\nabla\cdot\boldsymbol{u})\boldsymbol{I}+C(\nabla\cdot\boldsymbol{w})\boldsymbol{I}\\
&\qquad+G_{\rm b}(\nabla\boldsymbol{u}+\nabla\boldsymbol{u}^{\rm T}),\\
&-p=C\nabla\cdot\boldsymbol{u}+M\nabla\cdot\boldsymbol{w},\\
&\boldsymbol{D}=\varepsilon_0\Big[\frac{\phi}{\alpha_\infty}(\varepsilon_{\rm fr}-\varepsilon_{\rm sr})+\varepsilon_{\rm sr}\Big]\boldsymbol{E},\\
&\boldsymbol{B}=\mu\boldsymbol{H}.
\end{aligned} \tag{12}$$

Those governing equations are the Biot equations for porous medium acoustics along with the Maxwell equations for the electric and magnetic fields $\boldsymbol{E}$ and $\boldsymbol{H}$. Here τ is the bulk stress in the porous medium, p is the pressure in the pore fluid, $\boldsymbol{u}$ is the displacement in the solid, and $\boldsymbol{w}$ is the relative fluid–solid motion. The symbol ρ denotes the bulk density of the porous medium, $\rho = (1-\phi)\rho_{\rm s} + \phi\rho_{\rm f}$, where ϕ is the porosity of the medium, $\rho_{\rm s}$ is the solid density and $\rho_{\rm f}$ denotes the fluid density. The fourth and fifth equations are in the form of Darcy law and Ohm's law, through which acoustic and electromagnetic fields are coupled. Here, $\boldsymbol{J}$ is the electric-current density; $-{\rm i}\omega\boldsymbol{w}$ is the Darcy filtration velocity; H, C, M, and $G_{\rm b}$ are four moduli of isotropic porous media;[26] α_∞ is tortuosity; ε_0 is vacuum permittivity; $\varepsilon_{\rm fr}$ and $\varepsilon_{\rm sr}$ are the relative permittivities of the fluid and solid respectively; $\sigma(\omega)$ is the frequency-dependent electrical conductivity of the medium; $k(\omega)$ is the dynamic permeability; η is the fluid dynamic viscosity; $L(\omega)$ is the frequency-dependent electrokinetic coupling coefficient. The expressions for $\sigma(\omega)$, $k(\omega)$ and $L(\omega)$ are given in Refs.[16–18].

The solution to the coupled equations of seismoelectric waves motions can be obtained by separating the basic fields $\boldsymbol{u}, \boldsymbol{w}, \boldsymbol{E}$ into their compressional, vertically and horizontally polarized shear components, and further expressing them in terms of scalar potential functions as

$$
\begin{aligned}
\boldsymbol{u} &= \sum_{j=\rm pf,ps} \nabla\Phi_j + \sum_{j=\rm sh,em} \nabla\times\Big[\Psi_j\boldsymbol{e}_z + \nabla\times(\boldsymbol{\Gamma}_j\,\boldsymbol{e}_z)\Big],\\
\boldsymbol{w} &= \sum_{j=\rm pf,ps} \alpha_j\nabla\Phi_j\\
&\quad + \sum_{j=\rm sh,em} \alpha_j\nabla\times\Big[\Psi_j\boldsymbol{e}_z + \nabla\times(\boldsymbol{\Gamma}_j\,\boldsymbol{e}_z)\Big],\\
\boldsymbol{E} &= \sum_{j=\rm pf,ps} \beta_j\nabla\Phi_j\\
&\quad + \sum_{j=\rm sh,em} \beta_j\nabla\times\Big[\Psi_j\boldsymbol{e}_z + \nabla\times(\boldsymbol{\Gamma}_j\,\boldsymbol{e}_z)\Big],
\end{aligned}
\tag{13}
$$

where Φ_j is the compressional wave potential; $\boldsymbol{e}_z$ is the unit vector in the z-direction; Ψ_j is the horizontal polarized shear potential; $\boldsymbol{\Gamma}_j$ is vertically polarized shear wave potential. Each of these potentials satisfies Helmholtz-type wave equation. The formulas of factors α_j, β_j (j = pf, ps, sh, em) can be found in Refs.[17,21,27].

Outside the borehole, because the radiation conditions prescribe no incoming waves existing at the position where r tends to infinity, the solutions are as follows:

$$
\begin{aligned}
\Phi_j &= \sum_{n=0}^{\infty} \gamma B_n^j K_n(\eta_j r)\cos(n\theta),\\
\Psi_j &= \sum_{n=0}^{\infty} \gamma C_n^j K_n(\eta_j r)\sin(n\theta),\\
\Gamma_j &= \sum_{n=0}^{\infty} \gamma D_n^j K_n(\eta_j r)\cos(n\theta),
\end{aligned}
\tag{14}
$$

which are similar to those in the presence of only acoustic fields with respect to an nth-order multipole source.[28,29] Here, $\eta_j^2 = k_z^2 - k_j^2$ ($k_j^2 = \omega^2 s_j^2$) are the radial wavenumbers of the seismoelectric waves, whose complex slowness $s_j (j = {\rm pf, ps, sh, em})$ expressions can be found in Ref.[17]. Here, B_n^j, C_n^j, and D_n^j, which characterize the outgoing seismoelectric waves, are functions of the axial wavenumber k_z and the angular frequency ω. Once $\boldsymbol{u}, \boldsymbol{w}$ and $\boldsymbol{E}$ are known, all other quantities such as stress tensor, pore fluid pressure and magnetic vector can be deduced from Eq.(12). The components of seismoelectric field can be written in terms of the potentials using Eqs.(13) and (14). The detailed expressions of those formulations can be found in Ref.[27].

4. Boundary conditions and resolution

The boundary conditions of seismoelectric waves[17] for a cylindrical interface at the position $r = a$ between a fluid and a fluid-saturated formation are

$$
\begin{aligned}
&u_r^1 = w_r^2 + u_r^2, \quad -p_{\rm f}^1 = \tau_{rr}^2, \quad 0 = \tau_{rz}^2,\\
&0 = \tau_{r\theta}^2, \quad P^1 = p^2, \quad E_\theta^1 = E_\theta^2,\\
&E_z^1 = E_z^2, \quad H_\theta^1 = H_\theta^2, \quad H_z^1 = H_z^2,
\end{aligned}
\tag{15}
$$

where the superscripts 1 and 2 represent the media inside and outside the borehole, respectively. With the expressions of w_r, u_r, τ_{rr}, τ_{rz}, $\tau_{r\theta}$, E_θ, E_z, H_θ, and H_z deduced from Eqs.(12)–(14), the boundary equation may be written in the form of matrix as

$$
MA = B, \tag{16}
$$

where M represents 9×9 complex matrices, whose elements can be found in Ref.[27], and

$$
\begin{aligned}
A &= \{A_n, B_n^{\rm pf}, B_n^{\rm ps}, C_n^{\rm sh}, D_n^{\rm sh}, C_n^{\rm em}, D_n^{\rm em}, A_n^{\rm E}, A_n^{\rm H}\}^{\rm T},\\
B &= \{b_1, b_2, 0, 0, b_5, 0, 0, 0, 0\}^{\rm T},
\end{aligned}
$$

where $b_1 = \epsilon_n[\eta_f K_{n+1}(\eta_f a) - nK_n(\eta_f a)/a]$ and $b_2 = b_5 = -\rho_f \omega^2 \epsilon_n K_n(\eta_f a)$. The unknown coefficients of interest, A_n, A_n^E, A_n^H can be obtained from Eq.(16).

5. Numerical results

In this section we present synthetic acoustic waves and electromagnetic field in the borehole excited by an eccentric acoustic monopole source. The model input parameters are the same as those in Ref.[22], but for the slow formation, we choose $K_s = 33.40 \times 10^9$ Pa, $K_b = 2.61 \times 10^9$ Pa, and $G_b = 2.83 \times 10^9$ Pa. The point monopole source is of a cosine pulse.[27,29]

In the space–time domain, the acoustic wave field and electromagnetic wave field have the following forms: $P(r,\theta,z,t) = p_0 + p_1 \cos\theta + p_2 \cos(2\theta) + \cdots$ and $H_r(r,\theta,z,t) = h_1 \sin\theta + h_2 \sin(2\theta) + h_3 \sin(3\theta) + \cdots$. In form E_z, E_r, H_θ are similar to P, and H_z, E_θ are similar to H_r. In the nonsymmetric fields p_1, h_1 and p_2, h_2 are similar to those in the fields excited by dipole and quadrupole sources[27] respectively. It is of advantage to obtaining the information about shear waves from the nonsymmetric field, especially in the low frequency ranges. If the acoustic transducer, electrode, and Hall effect magnetometer are positioned in the borehole fluid, one could measure acoustic, electric and magnetic fields, respectively. For example, we choose only some positions to record the full waveforms.

The electric and magnetic fields produced by dipole sources ($n = 1$) were mistaken as zero on borehole axis in Ref.[27], and recently, Guan *et al* have given it a correct explanation (see Eqs.(51) and (52) in Ref.[30]). In the present work, the electric and magnetic fields on the borehole axis are expressed as

$$\begin{aligned} E_1 &= \gamma_0(k_z A_1^E + \omega\mu A_1^H), \\ H_1 &= -\gamma_0(k_z A_1^H + \omega\tilde{\varepsilon}_f A_1^E), \end{aligned} \tag{17}$$

where $\gamma_0 = V_0(\omega) \mathrm{i} I_1(\eta_f r_0)/(2\eta_e)$. Since $I_0(0) = 1$ and $I_n(0) = 0$ for $n \geq 1$, we can see that, on the borehole axis, only p_0, E_{z0}, E_1 and H_1 can be recorded. Figure 1 shows the 2 kHz fast formation waveforms recorded on the borehole axis. The stronger Stoneley wave packets can be seen only in Figs.1(a) and 1(b), however, the wave packets, whose speeds are very close to those of shear waves, can be found in Figs.1(c) and 1(d). It shows that, if possible, we can measure the shear velocity on the borehole axis by recording E_1 or H_1. Also we can find that EM wave-packets in Fig.1(d) arrive at all receivers simultaneously, which corresponds to the EM wave of the formation.[30]

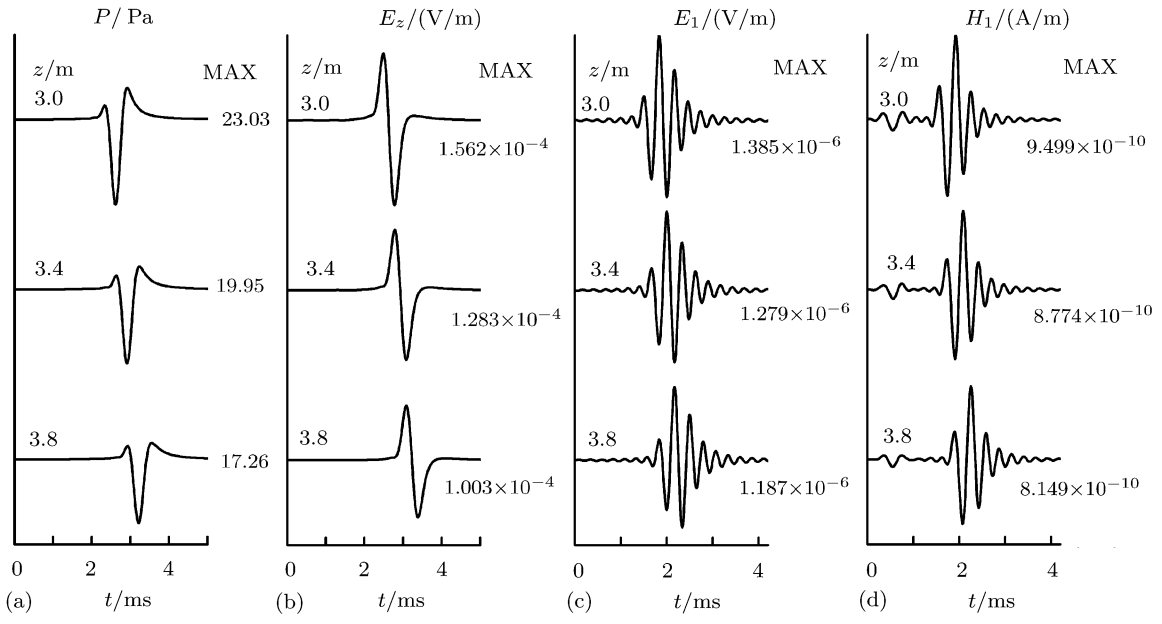


Fig.1. Waveforms of acoustic and electromagnetic fields received on the borehole axis for a fast formation with the parameters being. $r_0 = 0.05$ m, $r = 0.0$ m, and the central frequency 2 kHz: (a) is for P, (b) for E_z, (c) for E_1, (d) for H_1.

Figure 2 shows the 1kHz slow formation waveforms recorded on the borehole axis. The stronger Stoneley wave packets can be seen only in Figs.2(a) and 2(b). However, in Figs.2(c) and 2(d), the wave packets whose speeds are very close to those of shear waves can be found. It shows that, if possible, we can obtain the shear velocity on the borehole axis by recording E_1 or H_1. Also we can find that EM wave-packets in Fig.2(d) arrive simultaneously at all receivers. The above numerical examples show that one can obtain shear wave velocity by recording the converted nonsymmetric electric field and magnetic field on the borehole axis at low frequencies.

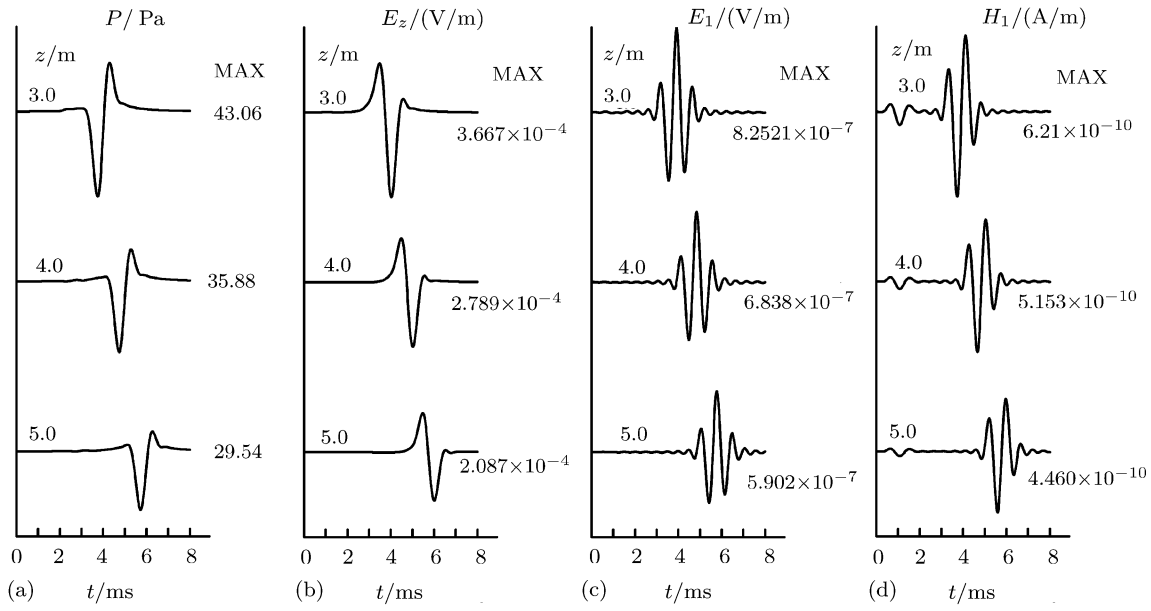


Fig.2. Waveforms of acoustic and electromagnetic fields received on the borehole axis for a slow formation with the parameters being $r_0 = 0.05$ m, $r = 0.0$ m, and the central frequency 1 kHz: (a) is for P, (b) for E_z, (c) for E_1, (d) for H_1.

Figure 3 shows electromagnetic fields received at $\pi/2$ azimuth for the fast formation, where the adopted parameters are $z = 3$ m, $r_0 = 0.05$ m, $r = 0.06$ m, and the central frequency 6 kHz. From Figs.3(a–c) we can find that the waveforms are similar to those of monopole waves, however, the waveforms of Figs.3(d)–3(f) are similar to those of dipole waves. In such a case, acoustic field P is described by $p_0 - p_2 + p_4 + \cdots$, and magnetic field H_r by $h_1 - h_3 + h_5 + \cdots$. Due to the small contribution from 'hexapole ($n = 3$)' and high-order terms, the waveforms of Figs.3(d–f) are very close to those of dipole waves. It indicates that one could obtain dipole waves by logging E_θ, H_r, H_z at $\pi/2$ or $3\pi/2$ azimuth. It may be a new method of directly measuring the shear wave velocity.

Zhang *et al*[29] provided an effective improved method of separating the components of the nonsymmetric and symmetric acoustic fields from the full waveforms. This method holds true for acoustic P and electromagnetic fields E_z, E_r and H_θ in the present paper. Here, we do not display the separation process. We pay our attention to obtaining the dipole waves from electromagnetic fields E_θ, H_r, and H_z better than those of Figs.3(d–f) and quadrupole waves. For example, the radial component H_r of magnetic field for a fast porous formation is shown in Fig.4, where the parameters are the same as those in Fig.3. If the two waveforms of H_r are logged at $\pi/3$ and $4\pi/3$ or $2\pi/3$(r and z are not changed), because of $\sin(3\theta) = 0$ for $\theta = \pi/3$, $2\pi/3$, $4\pi/3$, and $5\pi/3$, the waveform obtained by $[H_r(\pi/3) - H_r(4\pi/3)]/(2\sin(\pi/3))$ or $[H_r(\pi/3) + H_r(2\pi/3)]/(2\sin(\pi/3))$ is even closer to that of dipole wave than the above obtained (see Fig.3(e)), and the error is smaller than the term $\sin(5\theta)$. If the two waveforms of H_r are logged at $\pi/4$ and $5\pi/4$ or $3\pi/4$, because of $\sin(4\theta) = 0$ for $\theta = \pi/4$,

$3\pi/4$, $5\pi/4$, and $7\pi/4$, the waveform obtained by $[H_r(\pi/4)+H_r(5\pi/4)]/2$ or by $[H_r(\pi/4)-H_r(3\pi/4)]/2$ is closer to that of quadrupole wave,[27,30] and the error is smaller than the term $\sin(6\theta)$. The results show that adding and subtracting method is a better method of separating the dipole fields and quadrupole fields from the full waveforms excited by an eccentric source. Of course, such a method require us to make the receivers different from the usual tool. For the slow formation case, we can conduct similar operation but it is omitted here.

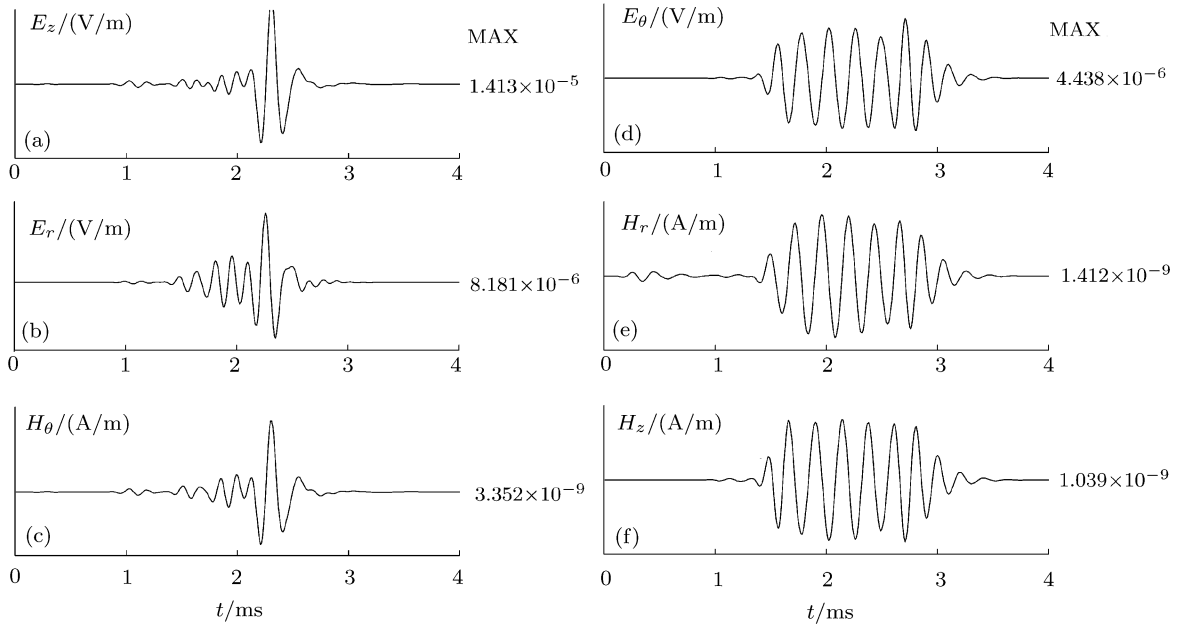


Fig.3. Waveforms of electromagnetic fields at $\pi/2$ azimuth for a fast formation with the parameters being $z = 3$ m, $r_0 = 0.05$ m, $r = 0.06$ m, and the central frequency 6 kHz: (a) is for E_z, (b) for E_r, (c) for H_θ, (d) for E_θ, (e) for H_r, (f) for H_z.

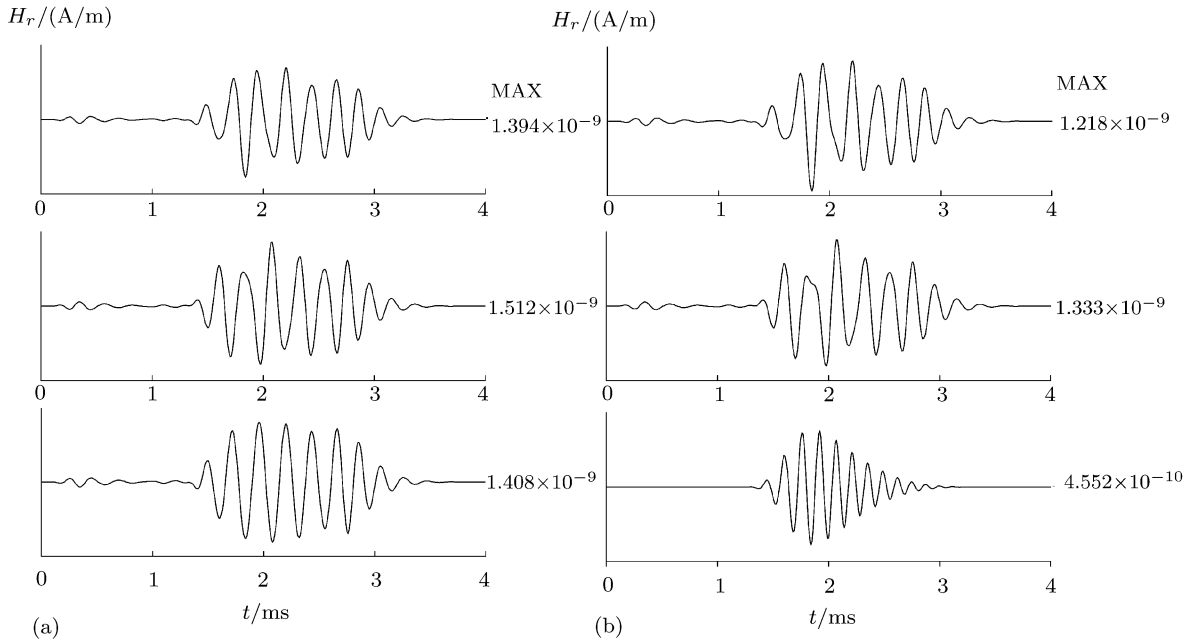


Fig.4. Waveforms of H_r for a fast porous formation with the parameters being $z = 3$ m, $r_0 = 0.05$ m, $r = 0.06$ m, and the central frequency 6 kHz. (a) The first curve(from top to bottom) is for $H_r(\pi/3)$, the second is for $H_r(4\pi/3)$, the third is obtained by $[H_r(\pi/3) - H_r(4\pi/3)]/(2\sin(\pi/3))$, (b) The first curve (from top to bottom) is for $H_r(\pi/4)$, the second is for $H_r(5\pi/4)$, the third is obtained by $[H_r(\pi/4) + H_r(5\pi/4)]/2$.

6. Conclusion

In this paper, an acousto-electric well logging method is presented based on the excitation and reception of the nonaxisymmetric acousto-electric field in a fluid-filled borehole embedded in permeable formations, excited by an eccentric acoustic source. The frequency wavenumber domain representations of the acoustic field and associated seismoelectric field are formulated. It is shown that acoustic, electric and magnetic fields are composed of an infinitude of the multipole fields with different orders. The numerical results show that two kinds of seismoelectric fields can be generated by acoustic waves in a fluid-saturated borehole. One can measure three components of both electric field and magnetic field. Measurement on the borehole axis will be of advantage to determining shear velocity information. One can obtain waveforms closer to those of dipole waves by recording electromagnetic components H_r, H_z and E_θ at $\pi/2$ or $3\pi/2$ azimuth. We can use the subtracting and adding method to separate the dipole fields from the full waveforms of H_r, H_z and E_θ received at $\pi/3$ and $4\pi/3$ or $2\pi/3$ with a smaller error and quadrupole fields received at $\pi/4$ and $5\pi/4$ or $3\pi/4$ from the full waveforms excited by an eccentric source. Borehole seismoelectric conversion many provides a new method of logging shear wave.

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