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Research Paper

Field Test And Challenge Of Electromagnetic Fracturing Monitoring

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Abstract: *Hydraulic fracturing is one of the key technologies for unconventional reservoir development. It is an important direction to evaluate the fracturing effect by electromagnetic detection in recent years. Based on the full study of the existing electromagnetic measurement and evaluation methods, a signal enhanced high-power time-frequency electromagnetic detection system was developed, and the field test of fracturing effect monitoring was carried out in Weinan oilfield. During the test, 38 measuring points are arranged according to the mountain topography of the oil well, and each point uses five component sensor signal to collect electromagnetic signal. Firstly, the high-power time-frequency constant current transmission is carried out before fracturing, and the three-component magnetic signal and two-component electrical signal of electromagnetic wave propagation are received. Then the high salt fracturing fluid is used to enhance the signal of fracturing volume. Finally, the electromagnetic signal after fracturing is measured again with the same transmission parameters. The measurement data before and after fracturing are processed by de-noising and Fourier transform to obtain the amplitude and phase information of the fracturing signal. The large difference signal indicates that the measurement signal before and after fracturing is abnormal, and the amplitude anomaly is stronger than the phase anomaly, which strongly indicates the spatial position of the fracturing interval, The effectiveness and feasibility of signal enhanced electromagnetic detection system for monitoring fracture are verified. Electromagnetic fracturing monitoring is still faced with many challenging issues, including: ① data processing and inversion methods, weak electromagnetic response and many influencing factors, how to carry out effective three-dimensional inversion imaging according to the surface measurement data; ② Structure characterization: the volume shape of fracturing usually presents complex network structure. How to effectively characterize the volume size and geometric shape of fracturing body; ③ Pattern matching: how to match and optimize the transmitting parameters, receiving modes and the downhole fracturing volume depth and scale; ④ Whether the signal strength produced by conductivity of fracturing proppant can meet the requirements of ground receiving and inversion imaging. In a word, electromagnetic detection system is of great significance for monitoring fracturing effect, optimizing drilling and completion design, and improving oil and gas well productivity. It is necessary to solve the existing challenging technical problems and vigorously develop signal enhanced electromagnetic detection system to realize the efficient development of unconventional oil and gas.*

Key words: *Reservoir fracturing; Electromagnetic monitoring; Time-frequency electromagnetic; Differential signal; Signal enhancement*

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I. Introduction

Unconventional oil and gas reservoir is the hot spot of exploration and development at present. Horizontal drilling and fracturing are two key technologies for its successful development[1-2]. After fracturing measures are implemented in oil and gas wells, economic and effective methods are needed to evaluate the fracturing effect. In order to overcome the shortcomings of traditional fracturing monitoring methods, oil companies, service providers and research institutions at home and abroad began to explore new fracturing monitoring technologies, and electromagnetic detection is one of the research focuses[3-5].

Electromagnetic detection technology is widely used in the exploration of metal deposits and oil and gas reservoirs. In recent years, it has been extended to the field of unconventional oil and gas fracturing development, and has achieved rapid development[6-12]. However, the existing detection technology and rating methods have some shortcomings, such as single detection mode, weak electromagnetic signal strength, inversion methods are still focused on two-dimensional inversion[13-17], and many information, such as fracture conductivity, geometry, complexity and orientation, can not be obtained. There are still many problems and challenges when applied to fracturing monitoring and evaluation[18-21].

Based on the full study of the existing electromagnetic measurement and evaluation methods, a signal enhanced high-power time-frequency electromagnetic detection method is proposed. Based on the hypothesis that the abnormal difference of response signals before and after fracturing comes from the change of fracturing volume and conductivity, the high conductivity fracturing material and electromagnetic detection system are developed, and the first field test of fracturing effect monitoring is carried out in Weinan oilfield in mountainous area.

1 Signal enhanced electromagnetic detection system

The signal enhanced electromagnetic detection system mainly consists of three parts: time-frequency constant current transmitter, multi-component array electromagnetic receiver and signal enhanced proppant material (Fig. 1).

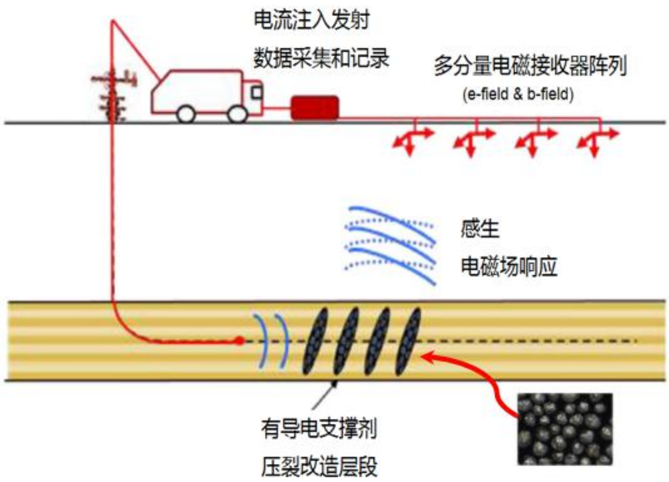

Fig. 1 Schematic diagram of EM fracturing image monitoring

In the process of measurement, the device near the wellhead is used to emit constant current to the underground along the metal cased well, and the electromagnetic excitation is applied to the downhole fracturing conductive support material. Because of the high conductivity of fracturing material, the excitation signal is enhanced, which is convenient to measure the electromagnetic induction signal on the ground. The higher the transmitting power, the deeper the detection depth of the system. The ground receiving device is composed of three-component magnetic sensor and two-component electrode. By reasonably arranging array measuring points, the underground fracturing volume space can be covered as much as possible.

2 Field test of electromagnetic fracturing monitoring

2.1 Electromagnetic test process of WB Oilfield

WB oilfield is located in the Yishan slope belt of Ordos Basin, where the mountains and forests are densely distributed and the height difference varies greatly. Most of the well sites do not have the measurement conditions. Through the exploration and selection of several well locations, the newly drilled well near a dry fish pond and a relatively flat mountain forest is determined as the test well. Over the perforating and fracturing wells, 38 irregular measuring points are arranged according to the terrain. The distance between the measuring points is about 50m. The electromagnetic emission electrode is connected to the wellhead, and the loop electrode is placed 575M away from the wellhead along the highway direction to ensure good grounding (Fig. 2). The ground electromagnetic data before and after fracturing are collected and recorded. Satellite time synchronization is used in the process of launch and data acquisition.

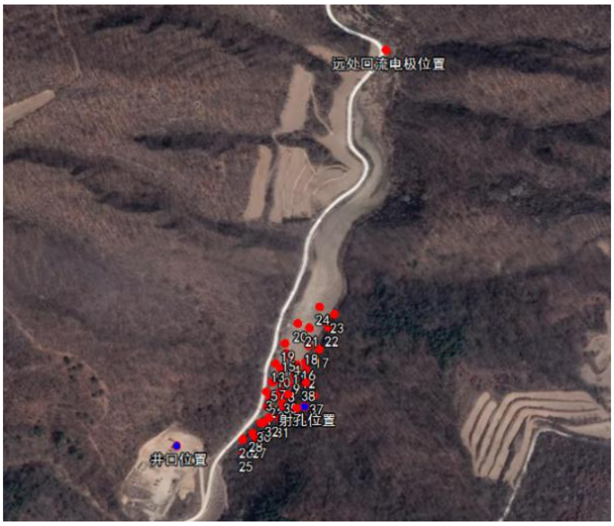

Fig. 2 Distribution of the EM receiver stations at the field test

By comparing the signal effects of different transmitting parameters and receiving parameters, the constant current excitation wave is determined to be positive and negative square wave, the frequency of excitation signal is 5Hz, the current is 17a before fracturing, the sampling frequency is 128 /s, the sampling time is 2mim, the ground receiving instrument collects the three components HX, hy and Hz of magnetic field, and the electric field ex and ey. The timing signal shows stable waveform and good consistency (Fig. 3).

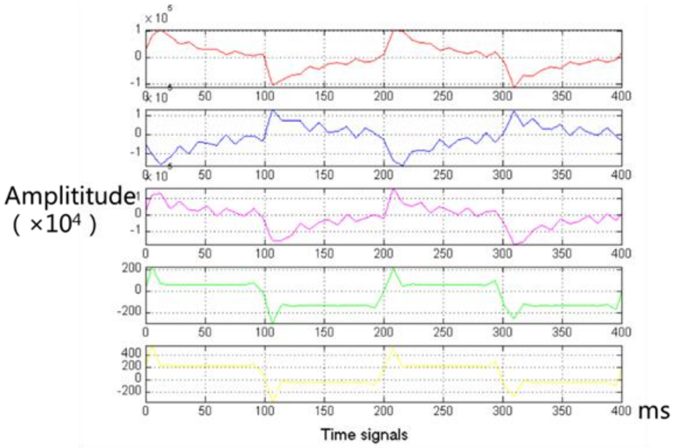

Fig. 3 Measured 5-component signal of EM field

2.2 Data processing of electromagnetic measurement

Because the received data is received by a single site, the actual received data is different time, so in the data preprocessing, we need to consider the matching relationship of parameters, frequency, time between different data, and reasonably extract the data window interval, so as to provide a unified data structure for subsequent processing.

However, it is more difficult to process the excitation signal because of the offset and interference of the sampling points in each period. The time domain amplitude superposition method, time-varying smoothing filtering method and time-varying bilateral filtering method are used to suppress the noise. According to the sampling period of the fundamental frequency signal, the time domain data of the electric field or magnetic field component is divided into windows, and Fourier transform is performed to calculate the real and imaginary parts of the fundamental, third, fifth, seventh, ninth and eleventh harmonic frequency of the five components of the electromagnetic field, and extract the amplitude and phase values of the corresponding frequency of each window (Fig. 4 and Fig. 5).

From the plane distribution diagram of magnetic field amplitude 4 - (a) ～ (c), it can be seen that the amplitude of HX, hy and Hz at and around the perforation location has obvious changes, and the amplitude of HX is the strongest,. According to the magnetic field phase plane distribution map 4 - (d) ～ (f), the abnormal signal at the fracture site is not very obvious, but there are local anomalies at the Northeast measuring points.

Whether it indicates the fracture extension direction remains to be further studied and confirmed.

From the distribution of electric field amplitude and phase, obvious signal anomalies appear in the vicinity of fracturing section, whether it is signal amplitude or signal phase. This shows that the measurement results can truly reflect the effect of reservoir fracturing. Through this field test, the feasibility and effectiveness of electromagnetic technology monitoring fracturing effect are verified to a great extent.

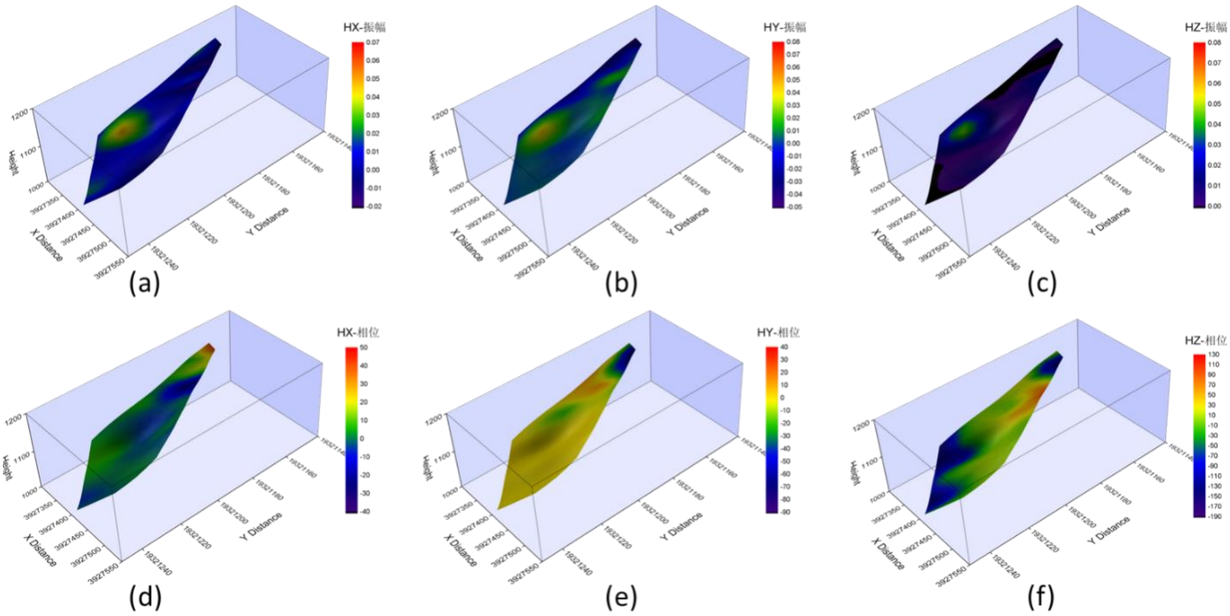

Fig. 4 Amplitude and phase distributions of differential b-field components

This is only the preliminary result of the field test. Due to the limitation of measurement conditions and geomorphology, the number of ground measurement points is too few and the distribution is not reasonable, and the fracturing section is not completely covered, which may affect the completeness of measurement data and processing results.

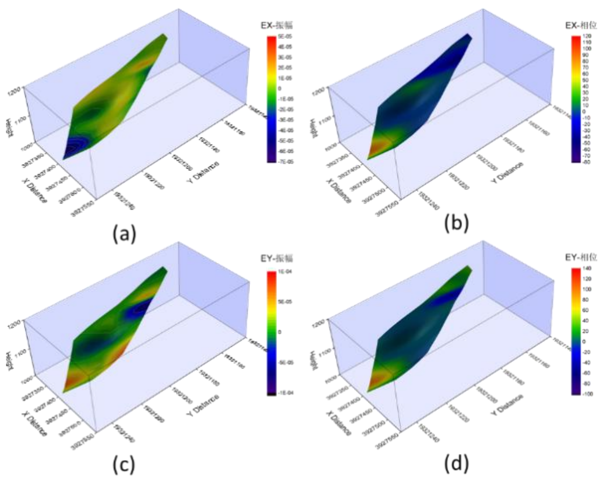

Fig. 5 Amplitude and phase distributions of differential e-field components

3 Challenges of electromagnetic fracturing monitoring technology

An electromagnetic detection system composed of high-power electromagnetic emission, multi-component receiving and signal enhancement technology has been established. The field test of fracturing monitoring has been carried out for the first time in China, and valuable test data and practical experience have been obtained, which verifies its technical feasibility and effectiveness. This new fracture detection system has the advantages of deep detection depth, high accuracy and effective characterization of abnormal body shape, but it also faces the following four challenges:

(1) Data processing and inversion methods. The inversion methods of electromagnetic sounding data can be divided into quasilinear optimization algorithm and global optimization algorithm. Quasilinear

optimization algorithm is a deterministic algorithm, including Gauss Newton, conjugate gradient, Occam, least square inversion and so on. It has the advantages of fewer iterations and faster inversion speed. However, its accuracy and convergence depend on the selection of initial model, and the inversion results are easily trapped in local minimum; Global optimization algorithm is a heuristic algorithm, including particle swarm optimization, simulated annealing, genetic algorithm and so on. It does not rely on the initial model and has strong global search ability, but its computing speed is slow.

The fractures formed by unconventional oil and gas pressure fractures present a complex network structure, which requires effective three-dimensional inversion based on surface measurement data. However, there are many factors affecting the electromagnetic response, such as low sensitivity, complex matrix calculation and difficulty in 3D inversion. Many models are no longer applicable, which challenges the efficient 3D inversion algorithm.

(2) Structure characterization technology. Generally, the electromagnetic method is used to detect the electrical abnormal body which is regular underground. For the irregular fracturing volume shape, it not only includes the length, width and height of the abnormal body, but also includes the extension trend and dip angle of the fracture, and even the cross extension interference between the fractures. In the process of forward and inversion of electromagnetic response, how to effectively characterize the size and geometry of fractured body brings challenges to the numerical processing and interpretation of electromagnetic response.

(3) Pattern matching method. The electromagnetic detection system consists of high-power electromagnetic transmitting and multi-component signal receiving devices, which have the matching problems of transmitting parameters, transmitting mode and received signal strength and receiving mode. The larger the emission current is, the greater the detection depth and ground signal strength are; The lower the transmission frequency and the deeper the detection depth, the weaker the ground signal strength. Therefore, in the process of measurement, it is necessary to determine the transmitting parameters and receiving mode according to the geological characteristics, depth and fracturing volume scale, and match the optimized parameters and modes, otherwise the detection effect and processing interpretation accuracy will be affected.

(4) Signal enhancement technology. In order to ensure the reliability and credibility of the monitoring effect, it is necessary to enhance the strength of the received signal on the ground. There are two methods: one is to increase the transmitting power and use high-power transmission (⩾ 60kW); The second is to enhance the conductivity of fracturing proppant. Using new conductive materials to enhance the conductivity of fracturing proppant is conducive to improving the measurement depth and ground signal strength of the detection system, and improving the inversion quality of electromagnetic data. The coating technology is used to realize the combination of high conductivity new material and conventional fracturing proppant to produce conductive proppant. However, how high the conductivity of conductive proppant can meet the requirements of signal receiving and data inversion, and whether the stability of the coating is reliable are challenging issues.

II. Conclusion

Unconventional oil and gas is the main field of oil and gas exploration at present and in the future. With continuous breakthroughs in horizontal wells and fracturing technology, electromagnetic detection system has broad application prospects in unconventional oil and gas development.

Through high-power constant current electromagnetic transmitter and multi-component electromagnetic receiver, combined with signal enhancement technology, the electromagnetic detection system is developed. The field test of fracturing monitoring was completed for the first time in China, which verified the technical feasibility and effectiveness.

Signal enhanced electromagnetic detection system is an important development direction in the future. It has obvious technical advantages. At the same time, it is difficult to study the technology and faces many technical challenges. It needs multi-party forces to cooperate in research and joint tackling.

References

[1]. Ma X H. "Extreme utilization" development theory of unconventional natural gas[J]. Petroleum Exploration and Development, 2021, 48(2): 381-394.
[2]. PU C S, ZHENG H, YANG Z P, et al. Research status and development trend of the formation mechanism of complex fractures by staged volume fracturing in horizontal wells[J]. Acta Petrolei Sinica, 2020, 41(12): 1734-1743.
[3]. Xiao Y, Li M. Research on application status of fracturing monitoring technology[J].Petrochemical Industry Technology, 2019, 26(07): 74-76.
[4]. Xie W B, Jiang Q Y, LI D C, et al. Interpolation analysis of hydraulic fracturing electromagnetic real time monitoring data based on random forest[J]. China Science and technology information. 2020(12): 88-89+12.
[5]. Duan J, Tang H, Wang Y. Detection technology of hydraulic fracturing in coalbed methane well based on microseismic and transient electromagnetic method. Coal Science and Technology, 2018, 46(06): 160-166.

[6]. Elliott P J. New airborne electromagnetic method provides fast deep-target data turnaround. Leading Edge, 1996, 15: 309–310.
[7]. Liu F B, Li J T, Liu H L, et al. Application of the EEMD method for distinction and suppression of motion-induced noise in grounded electrical source airborne TEM system. J Appl Geophys, 2017. 139: 109–116
[8]. Xue G Q, Chen W Y, Zhou N N, et al. Short-offset TEM technique with grounded wire source for deep sounding. (in Chinese) J. Geophys. 2013, 56(1): 255-261.
[9]. Di Q, Xue G, Yin C, Li X. 2020. New methods of controlled-source electromagnetic detection in China. Science China Earth Sciences, 63: 1268–1277.
[10]. Huang P. Application of transient electromagnetic method in detecting water accumulation in goaf of coalfield [J]. Natural resources of North China, 2021(02): 12-14.
[11]. Huang M, Song L. On Application of AMT and CSAMT to Geothermal Exploration——A Case of the Geothermal Exploration in Pingli River Pingtang County of Guizhou Province[J]. Chinese Journal of Engineering Geophysics, 2013, 10(03): 351-356.
[12]. Yang X H, Xu Z B, Zhang L J, et al. The application study of AMT in Chao-ge Tolgoi Cu-Pb-Zn polymetallic mining area of Mongolia[J]. Mineral Resources and Geology, 2021, 35(01): 113-118.
[13]. Zhu D P. 2-D joint inversion of magnetotelluric and magnetotelluric data [D]. China University of Geosciences, Beijing, 2015.
[14]. Thiel S. Electromagnetic Monitoring of Hydraulic Fracturing: Relationship to Permeability, Seismicity, and Stress[J]. Surveys in Geophysics, 2017, 38(1): 1-37.
[15]. Li M X. Research on the Anomaly Extraction Based on CNN and PSO-DLS Inversion of the Down-Hole TEM Method[D]. China coal research institute, 2020.
[16]. He J F. Comparison of 2-D magnetotelluric inversion methods: Study of REBOCC and DASOCC methods [J]. Progress in Exploration Geophysics, 2010, 33(1): 26-31.
[17]. Su Z L, Hu W B. 2-D inversion of magnetotelluric (MT) Sounding data by dimension descending approaching method[J]. Oil Geophysical Prospecting, 2002, 37(5): 516-523.
[18]. Wang, Kai, Dai, et al. Research on Monitoring Technology of Influence Range of Coal Mine Hydraulic Fracturing[C]// International Conference on Computational Science & Engineering. 0.
[19]. Mavromatou C, Hadjicontis V, D Ninos, et al. Understanding the fracture phenomena in inhomogeneous rock samples and ionic crystals, by monitoring the electromagnetic emission during their deformation[J]. Physics & Chemistry of the Earth Parts A/b/c, 2004, 29(4-9): 353-357.
[20]. Xu X X, Zhao X T, Wang B X, et al. Application and development on the Inversion Technique of the Magnetotelluric Sounding[C]//Geological Survey and Research, 2004.
[21]. Wei B J. A combined 1-D/2-D inversion algorithm of cross-hole electromagnetic fields [J]. Chinese Journal of geophysics, 2006, 49(1): 264-274.
[22]. Xu G Z, Yang Q X, Yan W L. Review of the development of modern electromagnetic technology[J]. Journal of Hebei University of Technology, 2000(03): 45-49.