https://doi.org/10.1051/e3sconf/202459802005

Research on Characteristics of Directional Impulse Sound Sources in a U-shape Connected Well

Jing Zhang* and Peng Zhang

PowerChina Huadong Engineering Corporation Limited, Hangzhou 311122, China

Abstract. The traditional U-shaped connected well connection technology mainly relies on the magnetic steering technology to guide the connection of the two wells, but the magnetic steering technology has the disadvantage of short detection distance. In order to increase the detection distance and ensure precise communication between the two wells, a new type of acoustic wave connection technology based on the impulse sound source was proposed in this paper. Firstly, an experimental study on the underwater impulse sound source was conducted and the characteristics of the sound source were analyzed in detail. The results show that the impulse sound source is a wide-band, high-energy, high-conversion efficiency source signal. The research on the sound field characteristics of the U-shaped connected well based on the impulse sound source can accurately locate the azimuth and distance of the target cased well, and provide technical support for guiding the drill bit to connect the target wellbore.

1 Introduction

As an important technology of unconventional energy exploitation[1-2], U-shaped connected well overcomes the shortcomings of low output and low efficiency of single well throughput technology, and has been widely used in both oil and non-petroleum industries[3-6]. However, in the U-shaped connecting well technology, how to ensure that the drilling tool assembly (horizontal well) can accurately detect the position of the target wellbore (vertical well) has become one of the important issues of widespread concerns at home and abroad.

To address this issue, early researchers represented by C. L. West and A.F. Kuckes developed ELREC (extended lateral range electrical conductivity) tools, Wellspot tools, Wellspot RGR tools, MGT (magnetic guidance tool) tools, etc. And the world's first U-shaped horizontal well was drilled by MGT tools. In 2001, A. G. Nekut and others developed the RMRS (Rotating magnet ranging system) tool. Since then, foreign companies such as Vector Magnetics have successively developed Wellspot tools, WSAB (wellspot at bit) tools and MagTraC tools. These tools all contribute to the detection of U-shaped wells, but they all belong to the category of using magnetic steering technology to control and guide the precise connection of U-shaped wells[7-8], and their maximum detection depth can reach 50m using RMRS tools.

The DRMTS long-distance needle threading tool, the electromagnetic vector guidance system and the SmartMag drilling mid-target guidance system have been independently developed in China for U-shaped well connection operations. The detection depth of the currently used magnetic navigation technology is 20 to 30 m. It is unable to detect more distant targets. In addition, domestic researchers have also proposed downhole radar drill bit positioning technology, but the detection distance is short and the construction is difficult.

The traditional U-shaped well connection technology mainly relies on magnetic steering technology to guide the connection of two wells, but the magnetic steering technology has the shortcoming of short detection distance. For this reason, some scholars have developed acoustic logging technology based on the sound source technology[9-10], which has attracted wide attention. E. A. Martin measured the maximum pressure of the arc channel during pulsed discharge by a specific experiment on the order of 10^4 atm. The drilling rig developed by SJ MacGregor et al can drill hard rock at a speed of 15 cm/min. Domestic researchers Yahong Sun, Ailong Fan and others have done a lot of experiments on the application of high-voltage electrical pulses in oil production. Liancheng Zhang and others from Zhejiang University also conducted technical research on pulsed plasma drilling rigs and achieved preliminary results.

However, the research on the characteristics of directional impulse sound source with drilling for U-well connection technology is not perfect. Therefore, this paper explores and studies the U-shaped well connectivity technology around the sound intensity characteristics, spectrum characteristics and energy accumulation characteristics of the plasma impulse sound source, so as to provide useful reference for engineering design.

* Corresponding author: zhang_j32@hdec.com

2 Study on Basic Characteristics of Underwater Impulse Sound Source

2.1 Basic Principles of Underwater Impulse Sound Source

Underwater impulse sound source mainly includes three processes, about discharge phenomenon, electrical breakdown process and bubble pulsation process. Discharge phenomenon is also known as electro-hydraulic effect. In an extremely short time (on the order of μs), a high-voltage electric field performs an underwater discharge process in a liquid medium with incompressibility and inertia. The electric breakdown process can be divided into three stages: the leading process of water molecule forming flow column on the electrode surface, the pre-breakdown heating process of water molecule temperature rising sharply in the ion channel and the spark breakdown process of underwater high voltage pulse discharge. Bubble pulsation refers to the process that the water-soluble medium in the discharge channel moves outward rapidly in the form of bubbles and forms pressure waves due to heating and evaporation.

2.2 Experiments of Underwater Impulse Sound Source

The underwater impulse sound source experimental device is shown in Fig. 1, which consists of a charging system, a discharging system, a charging and discharging control system and a data acquisition system. The device adopts high-voltage pulse discharge technology. First, the alternating current power is boosted to high voltage, and then it is rectified to charge the energy storage capacitor. When the stored energy reaches a critical value, the trigger circuit will generate a trigger pulse, thereby making spark gap switch close. The energy stored in the energy storage capacitor utilizes two discharge electrodes to perform instantaneous high-voltage discharge on the liquid gap between them, thereby generating a sufficiently large pulse shock wave.

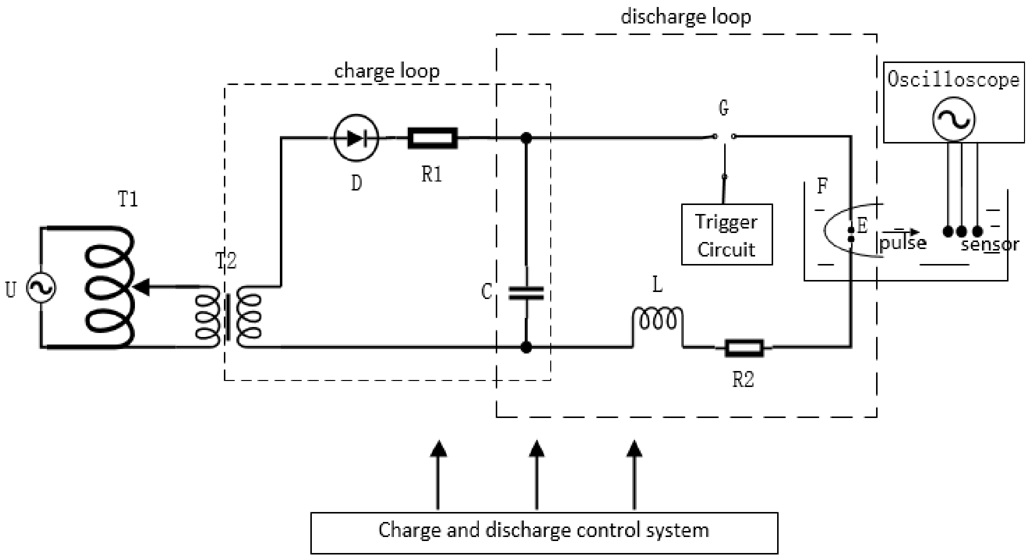

Fig. 1. Schematic diagram of experimental system of underwater impulse sound source.

In order to explore the characteristics of the underwater impulse sound source, the charging system adopts a constant voltage charging method, with a rated voltage of 50kV and a current of 0.1A. The discharge electrode in the discharge system can withstand a voltage of 25kV, and the gap distance between the electrodes when the current is greater than 25kA is about 0.8mm. The discharge process is powered by UPS, and the intermittent power supply capacity is 3000VA/2400W. The PCB pressure sensor is used, its range is 70MPa (input voltage is 5V)/138MPa (input voltage is 10V). The sensitivity (voltage/sound pressure conversion relationship) is 0.73 mV/kPa, the resolution is 0.14kPa and the temperature range is -18°C ~ +38°C. The PCB pressure sensor is about 16cm away from the center of the discharge electrode. By adopting a single variable method, keeping the energy storage capacitor unchanged (C=15μF) and other parameters unchanged (charging voltage is 20kV, energy storage is 3kJ), the experiments were carried out, and multiple sets of data were measured, and MATLAB was used to write a program for data analysis and processing.

2.3 Analysis of Electroacoustic Characteristics of Underwater Impulse Sound Source

In the experiment, read the discharge voltage and discharge current through the channel of the oscilloscope, and further calculate that the instantaneous power of the underwater impulse sound source device can reach the order of 10^8.

The underwater impact sound source will generate a pressure shock wave with large energy during the discharge process. In order to study its sound intensity characteristics, the sound pressure P, sound pressure level SPL and sound source level SL are defined as:

$$P = U_e / a \tag{1}$$

$$SPL = 20 \log p_e / P_{ref} \tag{2}$$

$$SL = 20 \log V + 40 \log R - M \tag{3}$$

where, U_e is the effective value of the measured voltage; a is the sensitivity of the pressure sensor, taking a = 0.73mV/kPa; P is the pressure of the sound source, in Pa; p_e is the effective value of the measured sound pressure; P_{ref} is a constant, taken as 1μPa in water; SPL and SL respectively refers to the sound pressure level of the underwater impulse sound source at a distance of 0.16m from the discharge electrode (that is, the location of the pressure sensor) and the sound source level at 1m.

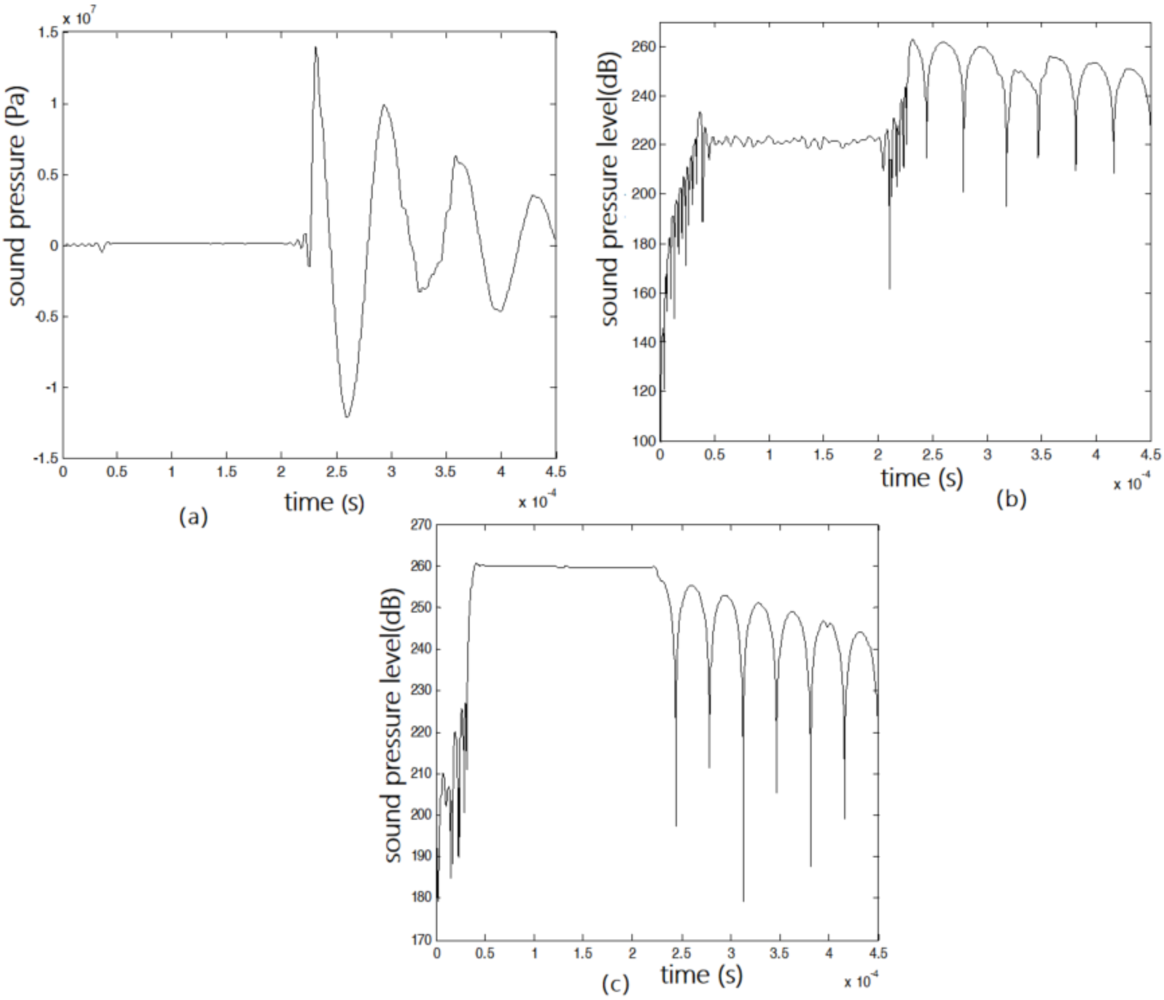

Fig. 2. (a) sound pressure-time diagram, (b) sound pressure level-time diagram, (c) sound source level-time diagram.

From Fig. 2(a), it can be seen that the initial pressure peak of the sound source is about 13MPa, which is the shock pressure wave directly generated by the discharge. The first peak appears at 0.23ms, and the channel is formed at 0.225ms. The time to the pressure sensor is 5 μs. And it maintains a relatively large sound intensity pressure value for a long time (0.2ms).

From the comparison of Fig. 2(b) and (c), it can be seen that the sound pressure level of the sound source reaches 262.9dB at 0.16m, and its sound pressure level remains within the range of 220~262.9dB for a long time. It can be seen that the sound intensity of the sound source is large. The sound intensity of the sound source propagating to 1m is 244.2~260dB. The comparison shows that the pressure of the sound source will gradually decrease with the increase of the propagation distance, which is caused by the attenuation of the energy during the propagation of the shock wave.

In addition to time characteristics, signals also have frequency characteristics. Based on the fast Fourier transform method, the sound pressure signal is analyzed in the frequency domain using MATLAB, and the results are shown in Fig. 3. It can be seen from the figure that the generated underwater plasma sound source has a large radiation frequency range, which can cover hundreds to hundreds of thousands of hertz, and has a large amplitude, especially in its low frequency band with a strong energy.

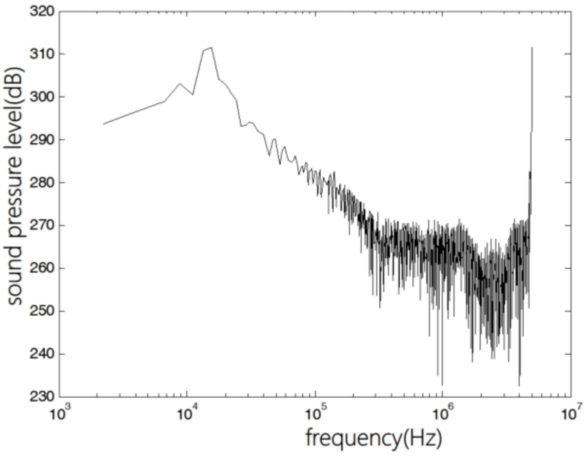

Fig. 3. Spectrogram of the sound source.

To calculate the sound wave energy, the following formula is defined:

$$W = 4\pi R^2 \int_{-\infty}^{\infty} P^2 \mathrm{d}t \Big/ \rho c_0 \quad (4)$$

where, c_0 is the speed of sound wave propagation in water, taking 1500m/s; ρ is the density of water, and P is the sound wave pressure at the measured point.

From formula (4), it can be easily calculated that the sound energy measured in this experiment at a distance of 0.16m from the sound source is 1514 J. Since the energy storage capacity of the energy storage capacitor is Wc=3kJ, its energy conversion efficiency is Z=W/Wc= 50%. To sum up, the underwater impact sound source can generate a wide-band, high-energy, high-conversion-efficiency sound source signal.

3 Conclusion

Through a large number of experiments and simulation studies on the characteristics of directional impulse sound sources, the following conclusions are drawn: The underwater impulse sound source is a broadband, high energy, high conversion efficiency, controllable and repeatable sound source signal. It can be applied to the connection of U-shaped connecting wells, which is a profound attempt for the connection of U-shaped wells. The research on the sound field characteristics of the U-shaped connected well based on the impulse sound source can accurately locate the azimuth and distance of the target cased well, and provide technical support for guiding the drill bit to connect the target wellbore.

References

1. Jin Z. Hydrocarbon accumulation and resources evaluation: Recent advances and current challenges [J]. Advances in Geo-Energy Research, 2023, 8(1):1-4.DOI:10.46690/ager.2023.04.01.
2. Kalu, Amadi O O C, Dozie J C, et al. A Review on the Geologic Occurrence, Development and Associated Environmental Problems of Unconventional Hydrocarbon Energy Resources[J]. 2020.DOI:10.38124/IJISRT20AUG809.
3. Sang S, Liu S, Cao L, et al.SYSTEM FOR EXTRACTING GAS FROM TECTONICALLY-DEFORMED COAL SEAM IN-SITU BY DEPRESSURIZING HORIZONTAL WELL CAVITY:US16960023[P].US20200340335A1[2024-08-28].
4. Che J, Wang H, Zhang Y, et al.Field test and numerical simulation of the section mill in U-shaped wells of coalbed methane[J].Journal of Natural Gas Science and Engineering, 2020, 84(2–3):103681. DOI:10.1016/j.jngse.2020.103681.
5. Diao B G D. A magnet ranging calculation method for steerable drilling in build-up sections of twin parallel horizontal wells[J].Journal of natural gas science and engineering, 2015, 27(Pta3).
6. Ning N, Wang H, Yong H. The unconventional natural gas resources and exploitation technologies in China[J].Natural Gas Industry, 2009.
7. Wu P, Wei M. Magnetization influence analysis of the casing and drill pipe in shale gas dual horizontal well Rotating Magnet Ranging System drilling process[J]. Energy Science and Engineering, 2020(4). DOI: 10.1002/ese3.730.
8. Dou X, Liang H, Fan J, et al. A signal acquisition and processing system for cluster wells ranging[C]//IEEE International Conference on Opto-electronic Information Processing. IEEE, 2017.DOI:10.1109/OPTIP.2017.8030692.
9. Gao X, Zhou J, Fu H, et al. Optimization for Emission Frequency of Oceanic Impulse Sound Source Logging[J]. Journal of Coastal Research, 2020, 111(sp1).DOI:10.2112/JCR-SI111-021.1.
10. Zhao Q, Che X, Qiao W, et al.Inversion of radial formation velocity distribution based on monopole acoustic logging while drilling[J]. Geoenergy Science and Engineering, 2023, 231.DOI:10.1016/j.geoen.2023.212313.