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Research and implementation of encoding and decoding technology of Layered Water Injection Based on Wave Code

Jian Zhao [1], Yang Li [2]

[1] Northeast Petroleum University, Daqing, China
[2] Purifier Branch of Daqing oilfield water Company, Daqing, China

Abstract: The layered water injection technology based on wave code communication is one of the fourth-generation separated layer water injection technology, widely used in low permeability oil field with pressure operation injection Wells, has the advantages of simple operation and low cost. However, there is a problem of low communication efficiency. In order to solve the problem of low communication efficiency, this paper compares the advantages and disadvantages of amplitude time modulation encoding and pulse position interval encoding, and proposes a method based on pulse position interval encoding and decoding. Finally, the pressure wave communication experiment is carried out. The results show that when the pulse width is set to 5s, the communication time of a set of opening instructions is only 3 minutes, which greatly improves the communication efficiency of the wave coding process. The research on encoding and decoding can provide technical and theoretical support for improving the communication efficiency of layered water injection based on wave code.

Keywords: Layered Water Injection Based on Wave Code; Pressure pulse; Amplitude time coding; Pulse interval coding.

1. Introduction

layered Water Injection technology development is the main way of oil field development in China. Daqing oilfield relies on water flooding development to maintain stable production of 50 million tons for 27 years, and more than 98% of Changqing oilfield's production comes from water flooding [1-2]. During the 13th Five-Year Plan period of PetroChina, the fourth-generation stratified water injection technology, represented by cable-controlled injection and wave code communication injection, was formed. Among them, the cable-controlled injection can realize real-time monitoring of downhole stratification parameters and online control of stratification flow through the way of external tubing cable [3], but the cable-controlled injection process cannot be applied to pressure operation. As Changqing is a low permeability oilfield, pressure operation mode is widely adopted in its injection Wells, which is mainly based on wave code communication and injection division mode. Two-way communication between surface and downhole is realized through fluid pressure pulse change [4]. Wave code communication injection separation technology has the advantages of simple operation and low cost, but the efficiency of wireless communication is low. It takes more than 2.5h to transmit a set of downhole data, while it takes 7-8h to test and commission a two-zone injection well. For multi-zone injection well, the test and commission time is longer, so it is mainly applied in the two-zone injection well.

As the amount of downhole data required to be collected and the transmission rate of pressure wave pulse signal increase, the difficulty of oil production becomes more and more serious. At the same time, the requirements for encoding and decoding technology also increase. The encoding method chosen will directly affect the quality of pressure wave pulse signal extracted from surface. The purpose of encoding and decoding the collected data is to reduce the errors in the transmission technology of pressure wave pulse signal and improve the effectiveness of the whole system. In this paper, the amplitude time coding and pulse position interval coding are compared, and finally the coding and decoding methods based on pulse position interval coding are designed, which can effectively improve the communication efficiency of wave code communication stratified waterflooding technology, and finally realize the purpose of efficient wireless wave code stratified waterflooding.

2. Principle of Layered Water Injection Based on Wave Code

The principle of layered water injection based on wave code. is shown in Figure 1. The communication between surface and well takes injected water as the medium [5]. When the ground controls downhole water distribution, negative pressure pulse is generated by changing the ground control valve, and the downhole water distribution device receives, decodes and drives the water nozzle to adjust the water injection amount [6]. When downhole data is uploaded, the positive pressure pulse is generated by the switch action of the downhole control valve, which is received and decoded by the ground control system to realize wireless uploading of downhole data.

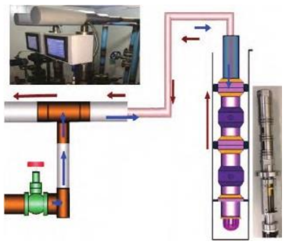

Figure 1. Schematic diagram of layered water injection based on wave code

Typical wave code communication coding methods[7] are shown in Figure 2: earth-oriented downhole instruction coding consists of "wake up code + layer code + opening code

+ end code", where: The wake up code represents to wake up the digital water distributor of each layer, the level code represents the level where the water distributor clearly executes the instruction, the opening code represents the opening value of the water distributor nozzle that should be opened, and the end code represents to prompt the end of the water distributor instruction. Layers are represented by time periods of different lengths, S is the length of instruction sending interval, and the encoding of different layers is the multiple of S.

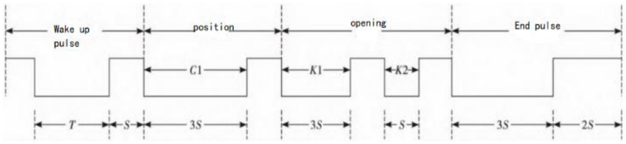

Figure 2. Typical wave code communication coding

3. Common pressure wave pulse coding techniques

Currently, the commonly used encoding methods of positive/negative pressure wave pulse signal mainly include amplitude time modulation coding and pulse position interval coding [8].

3.1. Amplitude time modulation coding

Amplitude time modulation is encoded to set a basic time unit T and transmit data in multiples of the basic time unit T [9-10]. When the signal changes, the value of the data is described in multiples of the basic time unit. Taking positive pulse time coding as an example, as shown in Figure 3, this coding method can greatly reduce the difficulty of signal recognition when there is a lot of interference, large amplitude fluctuation, unclear rules or difficult to identify and control. The disadvantage is that it takes a lot of time, which is not conducive to low signal transmission rate.

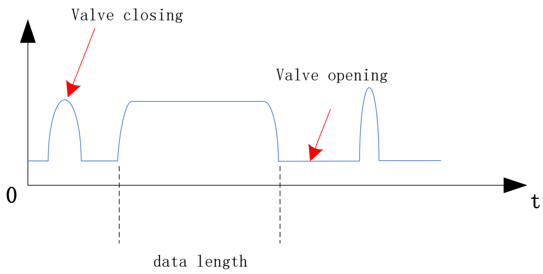

Figure 3. Amplitude time modulation coding

3.2. Pulse interval modulation coding

Pulse interval modulation coding is a modulation method that uses the time interval between two pulses to carry the required information [11]. Taking positive pulse as an example, the schematic diagram of pulse interval modulation principle is shown in Figure 4.

From the figure 2, it can be seen that the pulse position modulation only produces pressure deviation at the pulse moment, and the data can be expressed by a small number of pulses, which reduces the number of pulses sent by the pulse switch actuator and prolongs the service life of downhole communication equipment and downhole batteries. In addition, the pulse duration of the pulse position modulation code is short, the closing time of the pulse valve is short, and the effect on the water injection is small. Through the comparison of time coding and pulse position interval coding, pulse interval modulation coding can effectively improve the communication efficiency and effectively avoid the impact of pulse generation on the water injection. Therefore, pulse interval modulation coding is selected in this paper.

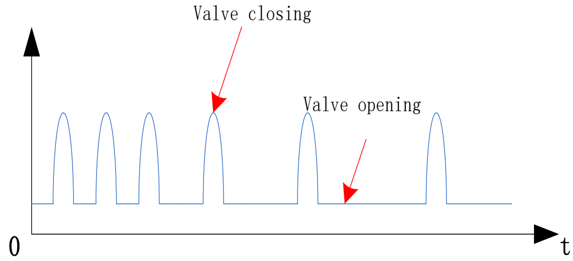

Figure 4. Pulse interval modulation coding

The relationship between pulse interval codes is shown in Equation 1:

$$Interval = MI + N * BW \qquad (1)$$

Where, MI is the minimum pulse interval duration, that is, the minimum interval between two adjacent pulses, represented by 0, and BW is the numerical bit duration. The pulse interval duration corresponding to a value N is equal to MI plus the duration of N. The value is represented by a four-bit binary code and can be regarded as hexadecimal data, that is, the value of data bits ranges from 0 to 15.

4. The encoding and decoding

4.1. Coding method

In the process of water injection, the pressure wave pulse communication data is bidirectional transmission, which can be divided into two communication modes: one is to send the water nozzle opening adjustment instruction to the underground surface; the other is to send the command to read downhole parameters to the underground surface, and the underground shall upload the temperature, flow rate and pressure data according to the command [11]. The method of real-time conversion of decimal and hexadecimal data is used to realize the bidirectional communication of pressure carrier technology. Define the data format based on data accuracy requirements and communication modes, as shown in Table 1:

Table 1. Data format

First identifier bit	destination address	source address	data length	data field	verify
1byte	1byte	1byte	1byte	1~96byte	1byte

The first identification bit is the synchronization head used for system communication synchronization, marking the arrival of data; The destination address is used to select which layer to control; The source address represents the address of the data read. Data length Select how many bytes to transmit. A maximum of 96 bytes is transmitted each time. Data field uses command + data, the first is command, followed by data; The verification code is used to determine whether errors occur during transmission of the whole set of data. The CRC8 verification is performed on the data from the first identifier bit to the data domain.

In addition, the reflection signal will be generated when the pressure pulse meets the change of flow area in the process of water injection pipeline transmission. In order to avoid the effective pressure pulse signal encountered by the reflected signal in the reflection process, which will cause attenuation of the pressure pulse signal and cause decoding error, it is necessary to set the valve closing time.

Since the reflected signal is generated by the reflection of pressure pulse, the formula of pressure wave propagation velocity is as follows:

$$c = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1+\frac{d}{e}\frac{K}{E}}} \tag{2}$$

Where, c is the propagation velocity of pressure wave, m/s; K is the bulk elastic modulus of liquid, N/m3; ρ is the density of water kg/m3; d is the inner diameter of the pipeline, m; e is pipe wall thickness, m; E is the bulk elastic modulus of the water injection pipeline, N/m3.

Since the reflected signal is generated by the reflection of pressure pulse, the formula of pressure wave propagation velocity is as follows:

$$\tau = \frac{2l}{c} \tag{3}$$

This paper illustrates how to calculate and combine with practical engineering. The water injection well carries water through the water injection pipe. The inner diameter, wall thickness and length of the water injection pipe are, the density of water, the elastic coefficient of water and the elastic coefficient of steel pipe.

Put the above parameters into (2) and (3), the pressure wave propagation velocity is 1367.20m/s, and the valve closing time must be greater than 1.76s.

Make coding rules according to the above requirements. The encoding mode of pressure wave pulse signal is as follows: Firstly, the standard pulse width is determined. In order to decode pulse width more accurately, three kinds of pulse width are mainly adopted, which are 3s, 5s and 10s. Then there is the sync head, which consists of three consecutive pulses, as shown in Figure 5.

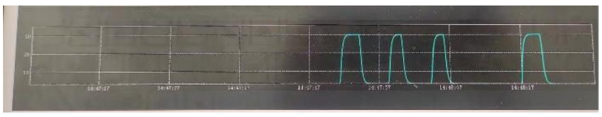

Figure 5. Sync head

According to the synchronization head and data pulse, the corresponding relationship between pulse interval and data can be judged: since the closing time of the valve should not be less than 1.76s, the time interval of the synchronization head signal, namely three continuous pulse signals, is set to 2.5s. The synchronization head signal is represented by s, and 0-F is used as the data signal. In order to distinguish synchronization signal from data signal, the minimum time interval of data pulse is stipulated to be greater than that of synchronization signal, so the minimum time interval of data pulse is set as 5s, and on this basis, one pulse width is extended, indicating "1". And so on, if a pulse occurs after a delay of 8 pulse widths, then this pulse represents "8".

Taking the pulse width of 1s and negative pulse transmitted from the ground as an example, the pressure pulse coding method is shown in Figure 6.

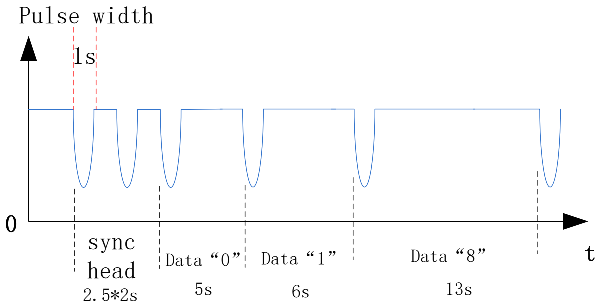

Figure 6. Ground transmission negative pulse code

4.2. Decoding method

Pressure wave decoding is the inverse process of encoding, which mainly includes data acquisition, synchronous recognition and real-time signal conversion [12]. Firstly, the original signal is filtered, and then the threshold value of the pressure wave pulse is determined by the peak detection method. The pulse higher than the threshold is retained and the pulse lower than the threshold is deleted. In addition, the software is required to monitor the synchronous head signal in the pulse signal all the time. Pulse position interval coding only contains useful signals in part time domain, so it is necessary to identify and extract these useful signals first, and then calculate the information contained in the pressure impulse signal of pulse interval coding through decoding algorithm.

Peak detection is realized by detecting the threshold pressure. Signals higher than the threshold pressure are useful signals, while signals lower than the threshold pressure are noise. Threshold pressure is detected by setting an effective signal detection threshold to find the position of pressure wave pulse signal, obtain pulse interval time, and then obtain data. According to the actual waveform, the threshold is determined to detect the peak value and calculate a group of peak spacing. In practice, the detection threshold must be set well, otherwise the noise will be regarded as a pulse signal, which will lead to data errors. When setting the detection threshold, an initial threshold can be set, and then the threshold can be manually adjusted according to the actual situation, so as to meet the requirements of field construction. Pulse interval time is obtained, and then data is obtained.

For the data encoded by pulse position interval, according to the pulse interval encoding formula described above, the decoding steps of pressure pulse signal are shown as follows:

First pulse decoding: a1=(I1-MI)/BW

Second pulse decoding: a2=(I2-MI)/BW

... ...

Decoding of the NTH pulse: an=(In-MI)/BW

Where, an is a non-valued negative integer and is the encoding parameter; MI is the minimum pulse interval duration, that is, the minimum interval between two adjacent pulses. BW is the length of the numerical bit, I1 is the distance between the first pulse and the synchronization head, and in (n > 1) is the distance between the NTH pulse and the previous pulse.

4.3. Experimental analysis

The experimental scene is shown in Figure 7.

Figure 7. Codec test experiment

The codec mode testing device consists of downhole communication equipment, complete machine testing equipment, remote pressure sensor, PC unit, as shown in Figure 8. Put the pressure sensor into the whole machine for testing, the other end is connected to the wireless transmitter, and the pc is connected to the receiver to receive the data collected by the pressure sensor.

Figure 8. Codec test

The pulse width is set to 3s, and the hexadecimal number corresponding to the sent data 20 is 14. Since the lower part is first and the higher part is last, it is contrary to the actual hexadecimal number, that is, the corresponding data bit of 20 is 41, and the synchronization code of data superposition frame is 541. It can be seen from Figure 9 that the software can decode successfully, and the decoding result is 541.

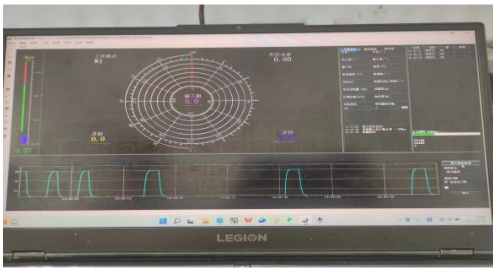

Figure 9. Codec test results

In order to further verify the reliability of encoding and decoding, the pressure wave communication experiment is carried out. The required tools are centrifugal pump, pressure sensor, wireless transceiver host, and a PC with injection dispensing software. Centrifugal pump is to provide water injection pressure and water injection, the pressure provided is continuous, and the output flow is the same, the change of frequency can provide different pressure. The pressure sensor monitors the pressure signal in real time, and transmits the signal collected by the pressure sensor to the PC connected to the wireless receiver through the wireless transmitter.

In the pressure wave communication experiment, the data sent is 20. 20 corresponds to the hexadecimal number of 14, since the low position is in the front and the high position is in the back, which is contrary to the actual hexadecimal number, that is, the data bit of 20 corresponds to 41, and the data is superimposed frame synchronization code. The actual sent data is 541. When the pulse width is set to 5 seconds and the pressure difference is 0.15~0.2MPa, the pressure waveform as shown in Figure 10 can be obtained.

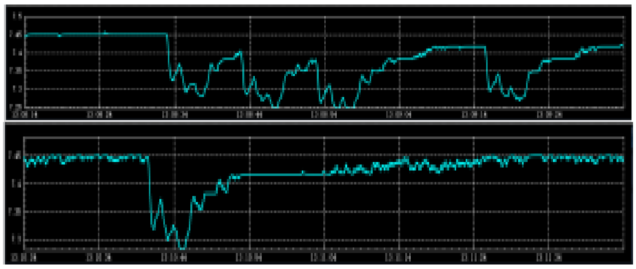

Figure 10. Pressure waveform diagram

According to the pressure waveform diagram in the figure above, the hexadecimal data obtained by decoding the pressure is 541, which is consistent with the sent data. In addition, it only takes 3 minutes to transmit a set of data. Therefore, the overall operation of the communication system is stable and the transmission rate is greatly improved, which fully verifies the reliability of the codec mode.

5. Conclusion

In this paper, the advantages and disadvantages of amplitude time modulation encoding and pulse position interval encoding are compared, and a method based on pulse position interval encoding and decoding is proposed. The problem of low communication efficiency of existing stratified water injection technology is solved. The main research results of this paper are as follows.

(1) Aiming at the low communication efficiency of wave code communication split-beam process, this paper designs the encoding and decoding mode based on pulse position interval encoding by comparing the advantages and disadvantages of amplitude time modulation encoding and pulse position interval encoding.

(2) The experimental results of pressure wave communication show that the codec mode proposed in this paper only needs 3 minutes to transmit a set of data, which greatly improves the communication efficiency and meets the design requirements.

References

[1] Liu H, Pei XH, Luo K, et al. Current status and development trend of stratified waterflooding technology in oil and gas fields in China. Petroleum Exploration and Development, 2013, 40(06): 733-737.

[2] Liu He, Pei Xiaohan, Jadli, et al. Connotation, application and prospect of the fourth generation stratified water injection technology. Petroleum Exploration and Development, 2017, 44(04): 608-614+637.

[3] Tong Y, Jin Z D, Liu J L, et al. Research and application of cable controlled stratified water injection technology in Daqing oilfield. Petroleum Science and Technology Forum, 2022, 41(03): 94-99+105.

[4] Yao B, Yang L Z, Yu J Z, et al. Research and application of digital stratified water flooding technique based on Wave Code Communication. China Petroleum Machinery,20,48(05):71-77.

[5] Wang E Z, Yang H E, Yu J Z, et al. Research and field application of layered water flooding technique based on wave code communication. Petroleum Science and Technology Forum,2022,41(03):100-105.

[6] Cheng Z, Xu Y, Gu C, et al. Research on pressure wave and communication of real-time testing and adjustable system in oilfield layered water injection//Proceedings of the Asia-Pacific Conference on Intelligent Medical 2018 & International Conference on Transportation and Traffic Engineering 2018. 2018: 208-212

[7] Zhao X S, Bai W X, Guo D, et al. Design and implementation of layered water injection device based on wave code communication. Oil Pipe & Instrument,2022,8(04):15-18.

[8] Kan J L. Research on Stratified water injection Communication Technology based on Pressure pulse. China University of Petroleum (East China),2020.

[9] Cheng, Z H, Kan K, Fan Z J, et al. Research on pressure wave transmission coding and implementation of testing and adjusting system for layered water injection in oilfield. Journal of Physics: Conference Series.2019.1345, 032050.

[10] Zhou Y, Chen H. Study on mechanism of layered water injection by pressure pulse control. Journal of Discrete Mathematical Sciences and Cryptography, 2018, 21(6): 1369-1372.

[11] Song X J, Dong C X. Positive pulse instrument coding while drilling. China Petroleum & Chemical Standards & Quality, 2013, 33(20):80.

[12] Yue Y L, Zhang H R, Geng Q, et al. Wireless communication method of water injection well based on pipe pressure wave. China Petroleum Machinery, 2021,49(02):81-87+132.