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Research Article

Wireless Monitoring of Downhole Pressure Based on Tubing Transmission

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Downhole pressure is an important parameter for evaluating the production status of production wells. A wireless monitoring system was designed for downhole pressure which consists of two parts, i.e., the downhole tool and the wellhead tool. The tubing was used as the information transmission medium between the two parts. The downhole tool includes four pressure sensors, and the measured results will be applied to the tubing in the form of an alternating voltage with a frequency of 2.5 Hz. The amplitude of the alternating voltage output by the downhole tool is related to the magnitude of the downhole pressure. The wellhead tool measures and decodes the signal uploaded through the tubing, and the decoded result will be transmitted to the host computer through the ground cable. The wireless transmission model of downhole pressure in the production well was equivalent to a resistance network. Simulation analysis indicates that the amplitude of the signal received by the wellhead tool is negatively correlated with the downhole depth of the downhole tool and positively correlated with the formation resistivity. The designed wireless monitoring system for downhole pressure was tested in gas-producing wells in southwestern China. The test results verified the stability and reliability of the system for downhole pressure monitoring. It also confirmed that the strength of the received signal at the wellhead is negatively correlated with the downhole depth of the downhole tool for the first time and is not affected by the structure of the wellbore. The wireless monitoring scheme of downhole pressure introduced in this paper can be extended and applied to the monitoring of other downhole parameters such as temperature.

1. Introduction

Downhole pressure is a critical parameter information for development well production status assessment and development plan adjustment [1–3]. Traditional formation pressure testing tools can acquire downhole pressure data at one time but cannot track downhole pressure change in development wells [4]. Traditional formation pressure testing tools are difficult and risky to operate for complex downhole environments such as horizontal wells and highly deviated wells. To track and detect the downhole pressure in the production layer of the development well, it is necessary to permanently place a downhole pressure measurement tool at a specific depth to track and monitor the change of the downhole pressure [5–7].

The use of permanent downhole parameter monitoring systems has been widely used in the oil and gas industry. Previously, the downhole parameter monitoring method based on optical fiber transmission was widely used in the industry. Similar downhole parameter monitoring solutions all require the use of cables for information transmission which is costly and requires higher process requirements for wellhead sealing [1, 8–10]. Therefore, the development of wireless monitoring technology for the downhole parameter has been paid more and more attention by the industry [11–14].

The existing wireless transmission methods of downhole parameters mainly fall into three categories: (i) information transmission using mud pulses, (ii) information transmission using acoustic waves, and (iii) information transmission using voltage signals. The first wireless transmission method has low transmission efficiency and is seriously affected by the properties of the fluid in the wellbore and the performance of the pump [15, 16]. Due to the complex structure of the wellbore medium, the mutual interference of acoustic waves is serious and their signal processing method is

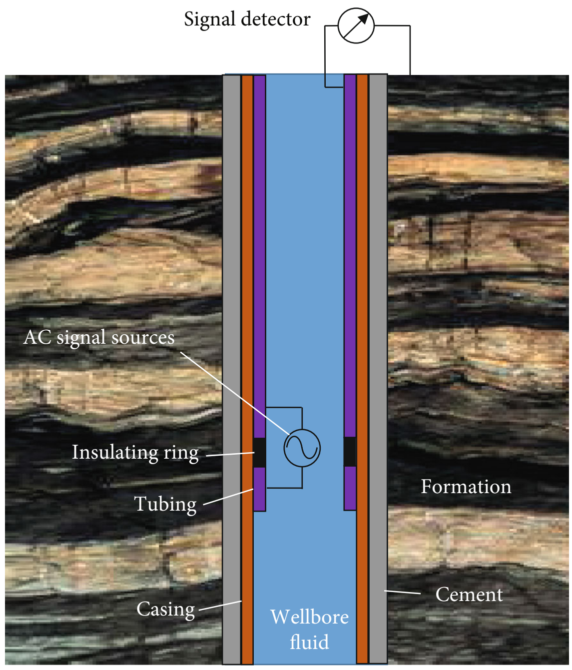

Figure 1: Principle of wireless monitoring of downhole pressure.

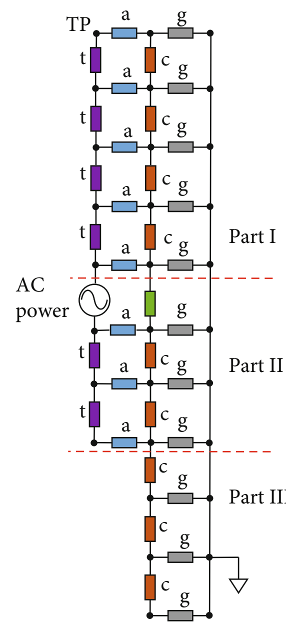

Figure 2: Equivalent resistor network of downhole pressure wireless transmission medium model.

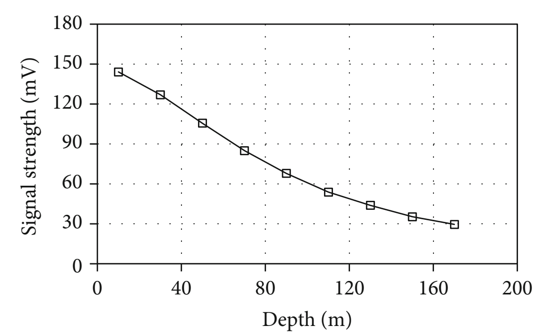

Figure 3: Relationship between received signal strength and downhole depth of the signal transmitter.

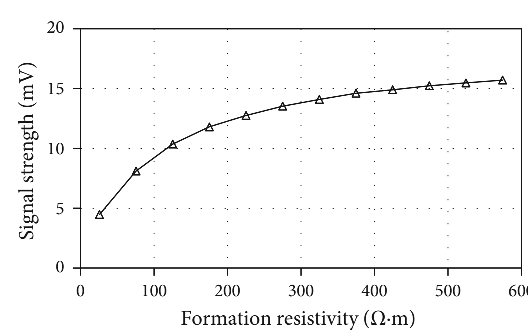

Figure 4: Relationship between received signal strength and formation resistivity.

complicated for the wireless transmission method of acoustic waves [17–19]. The third method usually uses tubing as a signal transmission medium [20–23]. This method has high received signal strength and high signal-to-noise ratio and is suitable for deep well downhole parameter monitoring because the tubing is a good electrical conductor. This paper presents a very simple tubing-based design of a wireless transmission system for downhole pressure which has been put into use in some gas production wells in southwestern China and has achieved good application results.

2. Methodology

2.1. Principle of Pressure Wireless Monitoring. The downhole pressure wireless monitoring system with tubing as the transmission medium mainly includes the downhole pressure signal acquisition and transmission system, the signal detection and transmission system near the wellhead. The principle of downhole pressure wireless monitoring is shown in Figure 1. The downhole pressure will be detected by the sensors at the measurement depth point, and an alternating voltage with a fixed frequency will then be applied to the tubing by the transmitting device which amplitude related to the downhole pressure. These assemblies are mounted on the tubing and are lowered into the well with the tubing during completion operations. The voltage signal can be propagated from the tubing to the wellhead and detected by the signal detector. The signal transmitting unit decodes the received signal into the corresponding downhole pressure signal and sends it to the host computer through the ground cable.

2.2. Model Simplification. The tubing, casing, wellbore fluid, and formation will form a complex impedance network in the transmission model of the downhole pressure signal. Referring to the finite element analysis method, each component in the model can be divided into several tiny resistance units so that the impedance of the complex transmission medium can be equivalent to the resistance network model

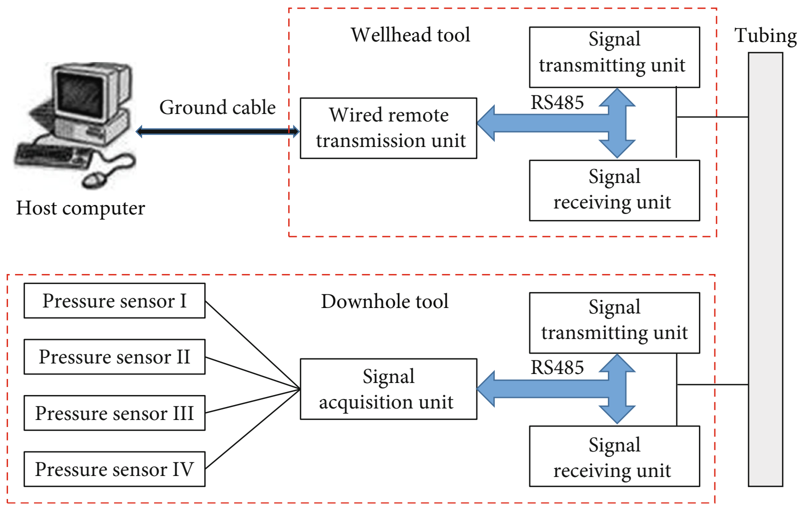

Figure 5: Circuit diagram of downhole pressure wireless monitoring system.

shown in Figure 2. The impedance network can be simplified into three parts longitudinally: the medium above the insulating ring (part I), the medium containing the tubing below the insulating ring (part II), and the medium below the insulating ring without tubing (part III).

In Figure 2, the resistor of type "t" represents the resistance per unit length of tubing, the resistor of type "a" is the contact resistance per unit length of tubing and casing, the resistor of type "c" is the resistance of per unit length of casing, and the resistor of type "g" is the grounding resistance of per unit length of casing. Apply an AC power to the junction of part I and part II, and use the circuit software to simulate the voltage at the wellhead node TP, which can explore the transmission characteristics of the signal on the tubing.

2.3. Signal Transmission Characteristics. During the simulation, the resistivity of the tubing was set to $2 \times 10^{-6}\,\Omega$·m, the resistivity of the casing was $1 \times 10^{-6}\,\Omega$·m, the contact resistance between the tubing and the casing per unit length was $10\,\Omega$, and the resistivity of the formation was set to $100\,\Omega$·m. The frequency and amplitude of the applied AC signal were set to 2.5 Hz and 0.3 V, respectively.

As shown in Figure 3, as the depth of the downhole signal transmitter continues to increase, the amplitude of the received signal at the wellhead continues to decrease. However, the attenuation speed of the signal amplitude decreases with the increase of depth; the longer the transmission path is, the more severe the signal attenuation will be.

The depth of the downhole signal transmitter was fixed at 300 m with other simulation conditions remaining unchanged to investigate the influence of formation resistivity on the amplitude of the received signal at the wellhead. It can be seen from Figure 4 that the greater the resistivity of the formation is, the greater the amplitude of the received signal will be. Because the impedance of the formation and the tubing is in a parallel relationship, the higher the resistivity of the formation is, the more likely the signal will propagate through the tubing with lower resistivity.

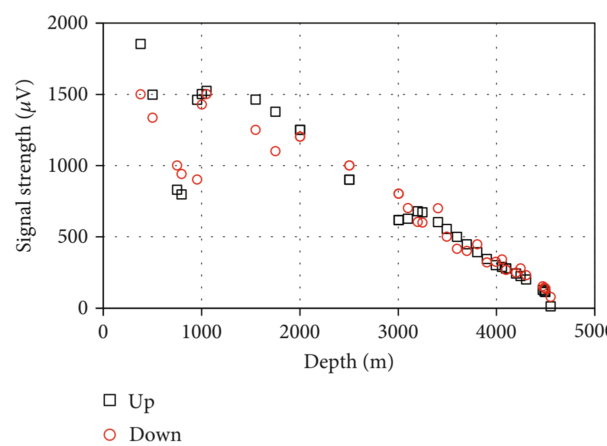

Figure 6: The relationship between the downhole depth of the downhole tool and the received signal strength of the wellhead tool in Well N77.

3. System Design

As shown in Figure 5, the downhole pressure wireless monitoring system consists of a wellhead tool and a downhole tool. The wellhead tool will send a control command to the downhole tool under the control of the host computer, and the downhole tool will start pressure acquisition and upload the measurement result when receives the control command from the wellhead tool. Then, the wellhead tool will decode the received signals and transmit the measurement results to the host computer. Both the downhole tool and the wellhead tool can be directly connected with the tubing.

3.1. Downhole Tool. The downhole tool contains four pressure sensors, and their output signals can be collected by the signal acquisition unit. The pressure signal will encode as an alternating voltage signal with a fixed frequency of 2.5 Hz and a varying amplitude under the control of the signal transmitting unit and applied to both ends of the

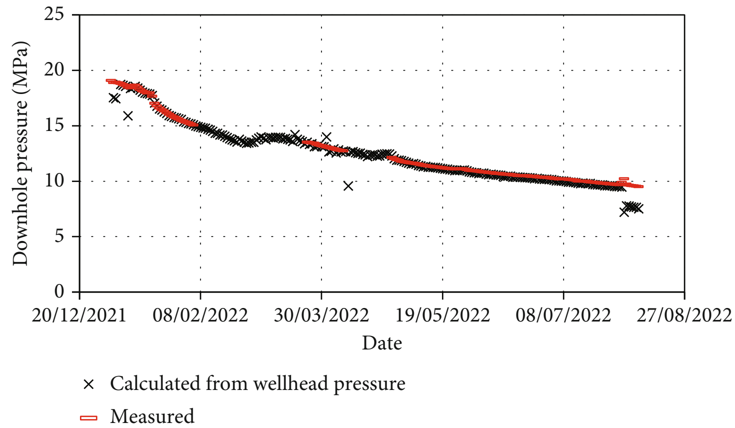

FIGURE 7: Variation of downhole pressure with the development time of Well N66.

insulating ring. The control command issued by the wellhead tool was also applied to the tubing as an alternating voltage signal with a frequency of 2.5 Hz for transmission. The signal receiving unit in the downhole tool receives and decodes the signal corresponding to the control command and controls the signal acquisition unit to start pressure measurement according to the decoding result. The signal acquisition unit, the signal transmitting unit, and the signal receiving unit exchange information through the RS485 communication protocol.

3.2. Wellhead Tool. The wellhead tool also includes a signal receiving unit and a signal transmitting unit, which are, respectively, used to receive the pressure measurement results uploaded by the downhole tool and send a control command to the downhole tool. The wellhead tool also includes a wired remote transmission unit which is connected to the upper computer through a ground cable. The instructions sent by the user through the host computer are decoded by the wired remote transmission unit and transmitted to the signal transmitting unit. The wired remote transmission unit will also upload the downhole pressure to the host computer after the signal received by the signal receiving unit is decoded. The wired remote transmission unit, the signal transmitting unit, and the signal receiving unit exchange information through the RS485 communication protocol.

4. Application

The downhole pressure monitoring system was tested in Well N77, a gas-producing well in southwestern China. Figure 6 shows the relationship between the downhole depth and the signal strength received by the wellhead tool during the process of lowering and lifting the downhole tool. The intensity of the signal received by the wellhead tool decreases approximately linearly as the depth of the downhole tool increases, which is consistent with the simulation results. The amplitude of the signal received by the wellhead tool can reach 80 μV, and the signal can be decoded normally when the downhole tool is lowered to 4600 m. Well N77 is an inclined well whose downhole depth is inconsistent with the actual vertical depth. Figure 6 also indicates that the strength of the received signal is mainly affected by the length of the metal tubing, and the formation resistivity has little effect on the received signal strength of the wellhead tool.

The downhole pressure monitoring system was used to detect and track the downhole pressure at the vertical depth of 2550 m in Well N66 which is also a gas-producing well in southwestern China. During the pressure monitoring, the wellhead pressure and fluid density are recorded. Since the well has no gas-producing zone above the test depth point, the pressure at the test point can be calculated using the produced fluid density and the wellhead pressure to verify the measurement results of the downhole pressure monitoring system.

$$P_D = P_H + \rho_l g H_v, \quad (1)$$

where P_D is the downhole pressure at the test point, P_H is the wellhead pressure, ρ_l is the density of the produced fluid, g is the gravitational acceleration, and H_v is the vertical depth of the test point.

Figure 7 shows the downhole pressure calculated from the wellhead pressure and produced fluid density and the downhole pressure change monitored by the monitoring system. It can be seen from the figure that the downhole pressure at the test point decreases gradually with the increase of development time. The downhole pressure recorded by the downhole pressure monitoring system is highly consistent with the downhole pressure calculated from the wellhead pressure and produced fluid density, which confirms the reliability of the downhole pressure wireless monitoring system.

5. Conclusion

This paper introduces a downhole pressure wireless transmission system with tubing as the signal transmission medium, which consists of a downhole tool and a wellhead tool. The transmission of downhole pressure information and surface control signals are all realized by applying a constant frequency alternating voltage to the tubing. Simulation results show that the strength of the signal received by the wellhead tool increases with the increase of the formation resistivity and decreases with the increase of the depth of the downhole tool.

The system was tested in gas-producing wells in southwestern China, and the measured data showed that the monitoring system accurately monitored the downhole pressure. The strength of the received signal at the wellhead decreases with the downhole depth of the downhole tool regardless of the wellbore structure. The wireless transmission scheme of downhole information introduced in this paper needs more realistic applications and can also be extended to the monitoring of other downhole parameters such as downhole temperature.

Data Availability

Data will be available on request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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