Study on the Measurement of Downhole Information on the Basis of Monitoring the Mud Pressure Pulse

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Abstract. Grasping the real-time and accurate downhole information is an important step for realizing optimized drilling, which is also the direction of many drilling companies. Because there are many types of signals with different amplitudes and frequencies that change all the time, in the meantime the signals are generated from sources far away from the ground as well as high temperature and high pressure appear in these positions, leading big challenges in measuring these signals. Measuring approach based on mud pressure pulse is one of the most popular methods used today. For this approach, sensors are placed downhole to monitor the information and the information is sent to the mud channel in the form of pressure pulse, then the sensors and systems on surface are used to treat these mud pulses. In this paper, the mechanism of the measuring the downhole information via mud pressure pulses is presented, including the emission of the downhole signals, the attenuation of the mud pressure in the mud channel, and the handling of the signals on surface. Based on the existing technology, some optimization measures are developed in the point structure of the mud channel, emission of the downhole signals, and disposing of the surface signals. In addition, the detailed operation procedures are also presented.

Introduction

Optimized fast drilling is one of the objectives pursued by the drilling companies. It means not only the request of a high rate of penetration, but also the seeking of good wellbore quality, the minimum drilling failures, and the lowest drilling cost [1]. There are many factors that influence the optimized fast drilling, including the rock formation, wellbore structure, and the drilling technology [2]. Because the target formations of the oil and gas are usually several thousand meters away from the surface, grasping the characteristics of these formations and the physical properties and dynamics of the drilling process (such as pressure and ) is of great difficulties. Measurement while drilling (MWD) and Logging while drilling (LWD) are technologies widely used. These technologies are used to monitor the downhole information so as to determine the control approach [3]. For these technologies, how to measure the downhole data is a big challenge. The application of mud pulse telemetry put a way to solve the trouble presented, however, many problems are needed to be settled [4].

The mud pulse telemetry is carried out by installing downhole sensors to measure the downhole data, the data are coded and then converted into pressure signals, then the pressure signals propagate in the mud channel and are monitored by the sensors set on the ground. The signals received by the sensors are decoded the processing system. During the process of the signal transmission, attenuation and distortion occur, especially for deep wells and drilling mud with high viscosity [5]. In addition, there are many factors that impact the obtaining of downhole data, including the mud property, drillstring structure, placement of the sensors, surface piping, and the mud pump [6]. Unquestionably, the transmission of the downhole data is important. In fact, there are also other important factors, such as downhole monitoring and data processing. Because there are many types of data in the borehole,
such as pressure, temperature, and vibration, and the measurement is a challenge work [7]. For the vibration signals, the lateral, axial, and torsional vibrations as well as the coupled vibrations may be included [8]. For those signals, their characteristics are different in the amplitude and frequency.

The use of MWD is to know the downhole real-time conditions, and then adjust the technologies and operations to optimize the drilling. Klotz [4] conducted research on the emission of the downhole signals and Emmerich [6] studied the transmission of the signals in the mud channel. Tu et al. [9] investigated the use of MWD to measure the signals received by the surface receiver. Tang et al. [10] investigated the error source of MWD. In this paper, the attenuation mechanism of mud pulse signals is studied, and the emission, transmission, receiving, and processing of the downhole signals are also included.

**Generation and Transmission of the Downhole Signals**

For the drilling tools, downhole sensors are installed to measure the signals. Each sensor is connected to an emitter, a rotational valve is driven by a motor connected to the emitters. In normal condition, the rotational valve rotates with a constant speed. In this way, the frequency of the mud pulse can be determined (Fig.2). After coding the signals through phase conversion, the valve is accelerated or decelerated in a small period of time and pressure waves are generated. The rotational valve rotate in a plane perpendicular to the borehole axis, which also means the rotational valve moves normally to the direction of the flowing mud [11].

For the signals, distortion occurs during the process of transmitting from downhole to surface. Then, the signals received by the surface receiver can be given as:

$$r(t) = s(t) * h(t) + n(t)$$

Where $s(t)$ is the signals emitted by the downhole measurement apparatus, $h(t)$ is the distortion factor of the mud channel, $*$ is the convolution operator, and $n(t)$ is the addition noise.
\[ T = \frac{4A_1A_2}{(A_1 + A_2)^2} \]  

(2)

Where \( A_1 \) is the original sectional cross area of the mud channel and \( A_2 \) is the new sectional cross area of the mud channel.

In fact, the transmission of signals is also related to the distance of the mud channel and the mud property. For the attenuation of the mud pulse, Hutin et al. [12] presented the formula of calculating the signal amplitude obtained on surface:

\[ P(x) = P_0 e^{\frac{-2x(\omega \eta)}{d_i \sqrt{2\pi B}}} \]

(3)

Where \( P_0 \) is the amplitude of the signals in the downhole source, \( x \) is the distance of the mud channel, \( d_i \) is the inner diameter of the mud channel, \( \omega \) is the angular frequency of the signals, \( \eta \) is the viscosity of the mud, and \( B \) is the bulk modulus of the mud.

**Generation and Transmission of the Downhole Signals**

For the downhole measurement, the receiving of signals on surface is another part of the important steps. During the measuring process, pressure sensors are set to receive the signals, and then the signals are input to the data processing system. In this system, the analog signals are converted into digital signals, and then noise cancellation is conducted. Finally, the signals are decoded in the computer, and the downhole information is obtained in this way.

Because of the distance of the mud channel and the mud property, attenuation and distortion occur for the signals obtained by the surface receiver. The surface pipes and pumps play important role in impacting the signal qualities. For the pumps, noises occur during the reciprocating motions and this is related to the pump stroke. The frequency of noise generated by the pump can be given as:

\[ f_n = \frac{nS}{60} \]

(4)

Where, \( n \) is the harmonic order, and \( S \) is the pump stroke rate.

In order to settle the problem of signal distortion, special algorithm is used to reduce the noise during the process of signal acquisition and processing. Because there are many factors that influence the signal quality and the parameters change all the time, so the process of signal acquisition and processing is of great importance. Fig.3 shows the normal procedures of the data acquisition.

![Figure 3. Normal Procedures of the Data Acquisition.](image)

During the process of decoding, automatic identification and decoding synchronization are required. Then, the interference suppression and noise cancellation are also used in the process of decoding. Because the delay effect appears during the signal propagates from downhole to surface, so how to deal with this effect is an important work. Based on this condition, Klotz et al [13] developed a type of flexible downhole emitter by which the desired parameters can be selected by controlling the emitted frequency. For this system, a surface processing system with advanced algorithm is used. By conducting a series of field tests, an optimized performance of the system has been proven. However, in some harsh conditions, for example deep well and vibrate sharply, the system did not show a high quality performance.
Optimization of the Monitoring System

Mud Channel

According to the Eq.(2), when the cross sectional area of the mud channel changes, part of the signals cannot pass. For example, once the mud channel changes from 66 mm to 139.7 mm in inner diameter, then about 80% of the signals pass and 20% of the signals are reflected. In addition, the pressure waves propagate in the form of vibration waves, they will attenuate because of the damping effect. If the signals generated downhole are not strong enough, then the data obtained on surface will be very weak. As a result, in order to reduce the signals attenuation, variation of the cross sectional area should be avoided.

Downhole Emission

During the monitoring of the downhole signals, we always want to obtain more data with large bandwidth so that we can know more about the downhole condition [14]. Because the signals contain noises and distortion, so these different types of downhole signals should be separately transmitted. Based on this condition, an emitter with better flexibility should be used, by which baseband modulation and decoding of the pulses are supported.

For the deep drilling and drillings with high viscosity mud and compressed mud, amplitude shift keying can be used to generate low frequency signals so as to reduce the signal attenuations. When using this approach, the signals are usually less than 10 Hz. Of course, negative effect may be formed even the signals transmitted in this way have small energy. Amplitude shift keying can adjust the signals to be in a certain frequency range, if the maximum carrier frequency is determined, then a high signal to noise ratio is to be found in this frequency range. Usually, the chance of obtaining a high signal to noise ratio is higher if the more carrier frequencies are supported.

In order to realize the transmission of signals with different frequencies, the rotational valve shown in Fig. 2 will be used to generate signals. For different types of signals, angular velocity of the rotational valve changes. When the rotational valve rotates, high frequency signals can be obtained with low velocity, and vice versa.

Surface Processing

In order to obtain high quality signals, two sensors can be installed on the stand pipe to measure the pulse signals. By doing this, diversity processing can be used to reduce the surface noises, such as
pressure vibrations generated by the mud pump. In normal drilling condition, signals generated on
surface have higher energy than the signals transmitted from downhole because attenuation exists [15]. For the signals obtained by the two sensors, demodulation and synchronization on the beginning of data processing are done. For the signals, special algorithm and diversity processing are used to reduce noise, including the noise from the pump. The data acquisition system converts the analog signals into digital signals, and the noise reduction can be processed in the digital system. For the decoding signals, they are displayed on the personal computer. Fig. 6 shows the procedures of the surface processing system.

![Diagram of procedures](image)

Figure 6. Procedures of the Surface Processing System.

Conclusions

Downhole information is very important for understanding the formation property, discovering oil reservoir, measuring the downhole pressure and temperature, and grasping the dynamics of the drillstring. The downhole signals can be measured by installing sensors. There are many types of signals, and the amplitude and frequency for each signal are different. In addition, the signals are transmitted through the mud channel, and thus there are still many challenges. In this paper, the mechanism of monitoring downhole data by using mud pressure pulse is studied, including the emission, attenuation, and surface processing of the downhole signals. Based on the exist technology, optimized measures are presented, including the structure of mud channel, downhole emission of signals, and surface data processing. Because part of the signals will be reflected back if the sectional area changes, so variations of the cross sectional area should be avoided. By using the amplitude shift keying, signals with different frequencies can be transmitted. For the surface processing, high quality data can be obtained by adding a sensor installed on the stand pipe.

References


