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STUDY ON TRANSMISSION CHARACTERISTICS OF MUD PULSE WAVES USED FOR TRANSMITTING INFORMATION FROM DOWNHOLE TO SURFACE IN DRILLING ENGINEERING

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In oil and gas drilling engineering, the drilling tool is driven into the earth from a drilling rig to create a wellbore through which hydrocarbons are passed. During the drilling process, it is desirable to collect downhole information about the drilling operation as well as the underground formations. Sensors are provided mainly in various portions of the downhole systems to obtain data about the trajectory, the earth formations, the operating conditions, and so on. The data is collected and analyzed so that decisions may be made concerning the drilling operation and the earth formations. So a key element of the steering process is the real-time measurement and transmission of the near-bit information from the bottom of the well to surface. The most commercial systems in drilling engineering for transmitting data to surface is to produce mud pressure pulses within the portion of the drilling mud enclosed in the hollow drillstring. In this technique, telemetry signals are encoded as mud wave pulses that propagate through the inside of drillstring and are subsequently received and converted back to electric signals for data recovery at the surface receiver. Based on the theoretical analysis, this paper will highlight the improvement of technical development.
Keywords: measurement while drilling, mud pulse waves, transmission

1. Introduction

In oil and gas drilling engineering, the drilling tool is driven into the earth from a drilling rig to create a wellbore through which hydrocarbons are passed. During the drilling process, it is desirable to collect downhole information about the drilling operation as well as the underground formations. Sensors are provided mainly in various portions of the downhole systems to obtain data about the trajectory, the earth formations, the operating conditions, and so on. The data is collected and analyzed so that decisions may be made concerning the drilling operation and the earth formations.

Nowadays, the directional and horizontal wells, as well as multi-branched horizontal wells have been the important technical approach to increase single-well producing rate and recovery ratio, and to achieve “less wells more production”. So a key element of the steering process is the real-time measurement and transmission of the near-bit information from the bottom of the well to surface.

The most commercial systems in drilling engineering for transmitting data to surface is to produce mud pressure pulses within the portion of the drilling mud enclosed in the hollow drillstring. In this technique, telemetry signals are encoded as mud wave pulses that propagate through the inside of drillstring and are subsequently received and converted back to electric signals for data recovery at the surface receiver. Mud pulse transmission is advantageous due to its reliability, low development costs, and ability to be applied to a wide variety of well depths, but the transmission rates in this way are at low levels.

The petroleum industry has long acknowledged the need for high-data-rate mud pulse telemetry in oil and gas exploration. This need is driven by several demand factors: high density logging data collected by more and more sensors, drilling safety for modern managed pressure drilling and real-time decision making, and management of economic risk by enabling more accurate formation evaluation information.

2. Working principle of pulse genetator

The information detected near the drill bit is transmitted to surface through the mud by way of data signals created downhole, which could be decoded by surface equipment. There are three types of downhole data mud pulse transmissions: positive pulse, negative pulse, and continuous wave.

A flow restrictor produces positive pulses as illustrated in Figure.1. Positive pulse telemetry uses a flow restrictor that closes to increase standpipe pressure when activated. As the mud flows through the pipe, the pressure fluctuates as the plunger mechanism opens and closes. The highs and lows of pressure, as sensed by a transducer on the standpipe, are transmitted to the surface as ones or zeros and are decoded as data.

A diverter valve produces negative pulses as illustrated in Figure.2. Negative pulse telemetry uses a diverter valve. When the flapper valve is open the drilling fluid is diverted to the annulus, creating negative pulses as the pressure fluctuates. The pressure changes are identified and decoded at the surface as data.

Mud sirens produce continuous waves as illustrated in Figure.3. Continuous wave pulsers, also known as mud sirens, are a type of positive pulse telemetry. Rotating baffled plates are used to temporarily interrupt mud flow, creating a pressure wave in the standpipe. A carrier wave is formed, allowing information to be embedded within the carrier wave by changing the wave's phase or frequency. The information carried by the wave is identified at the surface and decoded.

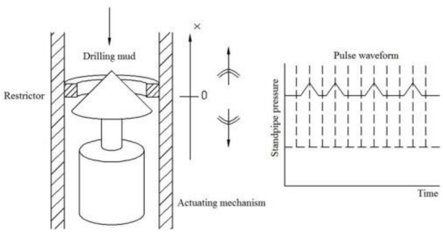


Figure 1:Diagram of positive pulse telemetry.

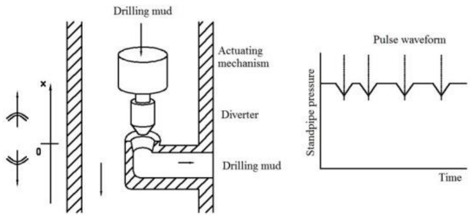


Figure **2**:Diagram of negative pulse telemetry.

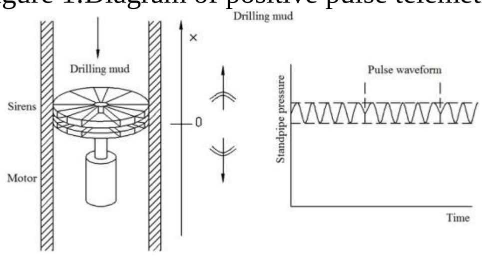


Figure **3**:Diagram of continuous wave telemetry.

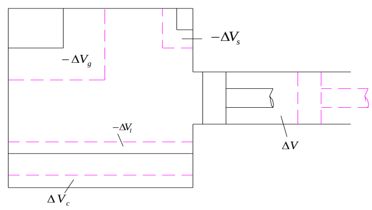


Figure **4**: Diagram for apparent elastic modulus.

3. Transmission velocity

In the mud pulse transmission system, the velocity of signal transmission is a basic parameter. However, the drilling fluid containing clay, cuttings, barite powder solid material, and the existence of discrimination from the state of the gas tends to form bubbles, thereby increasing the complexity of signal transmission speed. The calculation model of mud pulse propagation velocity is proposed here.

3.1 Apparent bulk modulus of elasticity

The sound velocity depends mainly on the bulk modulus of the fluid. Using the container shown in Figure.4, the apparent bulk modulus of elasticity for the system is studied.

Assuming that the piston is pushed toward the left ΔV, the pressure in the container increases to $p+\Delta p$, the apparent bulk modulus of the system can be defined as:

$$\frac{1}{E_{Ve}}=\left(\frac{1}{E_{Vc}}+\frac{1}{E_{Vl}}\right)+\beta_g\left(\frac{1}{E_{Vg}}-\frac{1}{E_{Vl}}\right)+\beta_s\left(\frac{1}{E_{Vs}}-\frac{1}{E_{Vl}}\right). \tag{1}$$

3.2 Velocity of pressure pulse wave

Using the deformation formula of the pipeline $\frac{dA}{A}=\frac{\Delta pD}{Ee}\psi$, we could get the transmission velocity for positive mud pulse signal as follow:

$$c=\sqrt{\frac{E_{Ve}}{\rho}}=\sqrt{\frac{E_{Vl}/\rho}{1+\psi\frac{E_{Vl}D}{Ee}+\beta_g\left(\frac{E_{Vl}}{E_{Vg}}-1\right)+\beta_s\left(\frac{E_{Vl}}{E_{Vs}}-1\right)}}. \tag{2}$$

While for negative mud pulse signal, the velocity is:

$$c=\sqrt{\frac{E_{Vl}/\rho}{1-\psi\frac{E_{Vl}D}{Ee}+\beta_g\left(\frac{E_{Vl}}{E_{Vg}}-1\right)+\beta_s\left(\frac{E_{Vl}}{E_{Vs}}-1\right)}}. \tag{3}$$

3.3 Summary and analysis

From the above analysis, we can get that the transmission velocity changes with different types of drilling fluids: when the density of drilling fluid increases, the velocity decreases; when the gas content increases, the velocity decreases sharply; the transmission velocity in water-based drilling fluid is higher than that of oil-based drilling fluid.

In conventional drilling conditions, the negative pulse signal transmission velocity is higher than the positive pulse signal of about 10%.

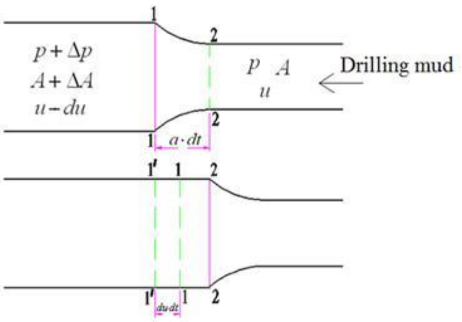
4. Transmission characteristics in flexible hose

From the drilling practice as well as the operation experience of measurement while drilling systems, the elasticity of flexible hose had an important influence on attenuation of the up-coming mud pressure pulses.

4.1 Mud pulse transmission model in flexible hose

In the mud pulse telemetry system, the transmission of the downhole signal and the mud flow inside the drillstrings are in the opposite direction. When mud positive pulse spreads to the right with velocity a, the mud flows to the left in flexible hose with velocity u, wave front reaches the “1-1” section at the time t. After time interval dt, the wave front moves to the “2-2” section, as shown in Figure.5.

Assuming the drilling mud in the flexible is static in the beginning, that means u=0, and the mud is not disturbed by the pulse generated in down hole before the reach of the wave front. After the wave front, because of the disturb of the pulse, the pressure increases to $p+\Delta p$, the cross-sectional area of the pipe enlarges to $A+\Delta A$, the velocity of the mud flow is –du. So the mud flow and the transmission of the signal are equal to the same direction at this time, as shown in Figure.6.



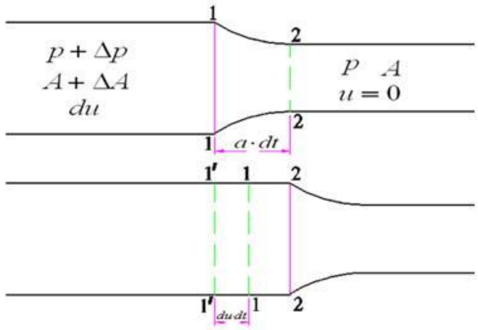


Figure **5**: Transmission of the pulse and the mud flow. Figure **6**: Equivalent schematic diagram of Figure 5.

With the equivalent method, as well as the continuity equation, motion equation and the property equation of flexible hose, the mathematical model for mud pulse transmitting in flexible hose can be got as follow:

$$\begin{cases} \dfrac{A}{\rho a^2}\dfrac{\partial p}{\partial t}+\dfrac{\partial q}{\partial x}=0 \\ \dfrac{\rho}{A}\dfrac{\partial q}{\partial t}=-\dfrac{\partial p}{\partial x}-\dfrac{8\eta\pi}{A^2}q \end{cases}. \tag{4}$$

4.2 Analysis and solution

On the basis of research methods in hemodynamic system, according to the actual condition of the mud pulse transmitting through the flexible hose, the parameterized transmission model can be derived based on the elastic cavity effect, the inertial and viscous effects. Then the hyperbolic partial differential equations can be solved by using the integral transform method. Finally, the transient expression of mud pressure and flow quantity for any point *x* can be calculated just as follow:

$$p(x,t)=\frac{\dfrac{p_0}{Z_0}}{1+\dfrac{Z_0}{Z_c}}\begin{Bmatrix} U(t-\dfrac{x}{a})+\delta_L U(t-\dfrac{2L-x}{a})+\delta_0\delta_L U(t-\dfrac{2L+x}{a}) \\ +\delta_0{\delta_L}^2 U(t-\dfrac{4L-x}{a})+\dots\dots\dots \end{Bmatrix}. \tag{5}$$

$$q(x,t)=\frac{p_0}{Z_0+Z_c}\begin{Bmatrix} U(t-\dfrac{x}{a})-\delta_L U(t-\dfrac{2L-x}{a})+\delta_0\delta_L U(t-\dfrac{2L+x}{a}) \\ -\delta_0{\delta_L}^2 U(t-\dfrac{4L-x}{a})+\dots\dots\dots \end{Bmatrix}. \tag{6}$$

From the form of the solution, the amplitudes of all reflected waves are never greater than the amplitudes of the incident waves. Therefore, the solution of the equations eventually tend to be of a gradual value.

5. Conclusion

According to the theory of unsteady flow, this paper discussed the formulas of transmission velocity for mud pulse, also analyzed the transmission of the mud pulse in the flexible hose, which provided a theoretical basis for the research of new methods to improve the signal strength and transmission rate.

(1) The transmission velocity of the mud pulse is sensitive to the gas content, and the solid content, for which is related to the density and compressibility.

(2) Under conventional drilling conditions, the negative pulse signal transmission velocity is higher than the positive pulse signal of about 10%.

(3) Because of the elastic of flexible hose, the constantly reflected pulse waves would affect the up-going signals detected at the standpipe, which includes the influence on magnitude and frequency of mud pulses.

(4) The reflection times in the flexible hose depends on the transmission velocity, which is also depends on the elastic of the hose. So we should choose suitable hose with proper elastic modulus.

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