A New Pulse Interval and Width Modulation (PIWM) Technique for Underground Drilling Fluid Measurement Systems

Deshu LIN [1], Caifeng CHENG [2*]

1. College of Computer Science, Yangtze University, Jingzhou Hubei, 434023, China

2. *Department of Information,* Yangtze University College of engineering and technology, Jingzhou Hubei, 434020, China

E-mail: ccf_cheng@126.com

***Abstract* — This paper presents a new Pulse Interval and Width Modulation (PIWM) technique for underground drilling fluid measurement systems. High bit error rate is problematic in the receiving device command recognition and interpretation. It is vital to accurately and efficiently identify the instruction signal transmitted at pulse intervals by the device. In PIWM the transmission capacity of the pulse code is larger than that of: i) pulse width modulation and ii) the different pulse position modulation code. By comparing the characteristics of PWIM technology and other modulation methods, this method can determine the parameters of the transmission system, where the code length is determined by the input signal, and synchronization is not considered since the code already contains this information. PIWM can save energy and accurately restore the source signal. Detection error and multipath transmission is easy to achieve. The paper gives the method instruction code suitable for underground processing, and a signal acquisition test device is designed and built. The results show that the method can simplify the operation process and improve the reliability and anti-interference ability of the signals, especially it overcomes: i) the influence of spikes, ii) the periodic disturbance on pulse recognition, iii) the influence of the transmission channel inertia, and the low frequency noise on accurately judging the signal jump.**

Keywords - Drilling fluid pulse modulation; Signal transmission technology; Modulation coding; Steerable drilling; Down-link signal

I. INTRODUCTION

In the 30's of last century, people began the research and application of the measurement technology with drilling. Baker Hughes, Schlumberger, Halliburton and other petroleum technology companies have developed wireless measurement while drilling tools. Along with the development of the measurement technology, the research and application of underground information real-time to the ground transmission technology has been more mature. At present, due to the emergence of a large number of complex structure wells, conventional drilling tools cannot meet the requirements of the development of the complex reservoir. To accomplish complex well trajectory, the direction of bit drilling must be controlled accurately. The core of the development of the well trajectory control tool is to change the joint force on the drill or to change the eccentric degree of the drilling tool under the working condition [1]. Well trajectory closed loop drilling technology is the development of advanced drilling technology at home and abroad, which is the focus and development direction of modern steering drilling. In the case of accurate control of downhole drill bit, the problem of drilling guide parameter must be solved, and the drill bit should be drilled along the well trajectory in advance. The signal transmission system is the key part of the automatic control system of the well trajectory, and it is an important bridge connecting the ground control system and the downhole bit guiding mechanism. It to thousands of meters deep well eye as a channel for the transmission of signals, is mainly responsible for the downhole condition and parameter monitoring and implementation of downhole control system oriented decision-making, intervention control function two-way communication tasks. Therefore, the signal transmission system is the key technology to realize the automatic control of well trajectory, which is directly related to the success or failure of the whole control system.

In the downlink communication technology of the well trajectory control system, the drilling direction parameters are mainly transmitted by mud pulse, insulated wire, electromagnetic wave, sound wave, intelligent drill pipe, optical fiber and so on[2-5]. Because of the underground working communication environment is very complex, there are advantages and disadvantages of several transmission medium, the transmission characteristics of the above transmission characteristics are shown in table 1.

TABLE 1 COMPARISON OF MEDIUM IN ROTARY STEERING DRILLING

Transmission Medium	Depth	Speed	Reliability	Cost
Drilling Fluid Pulse	>6000m	Slow	Good	Low
Insulated Wire	>6000m	Fast	Good	High
Electromagnetic Wave	600-6000m	Fast	Common	High
Acoustic Wave	<1000m	Fast	Common	Low
Optical Fiber	>6000m	Very Fast	Good	High
Intelligent Drill String	>6000m	Fast	Good	High

II. ANALYSIS OF THE TRANSMISSION CHARACTERISTICS OF DRILLING FLUID PRESSURE PULSE SIGNAL ALONG DIRECTIONAL WELL

In the wireless information transmission system of the ground and underground, the drilling fluid pressure pulse signal is transmitted in the drill string in the form of pressure wave. The transmission rate of the information is a basic parameter of the transmission mode. Information transfer rate of drilling fluid pressure pulse signal proportional to the carrier frequency, transmission rate information will vary with the carrier frequency increases. For the drilling fluid pressure transmission system, the transmission depth and transmission rate of the signal becomes the research focus of drilling information in the wellbore. In the pressure wave signal in drill pipe from the bottom of the well to the wellhead transmission process, due to the drilling fluid is a gas, liquid and solid three-phase flow, meantime it contains clay, cuttings, barite and other solid materials. It often has a free state of gas and other gaseous substances. Produced by the rotary valve of the drilling fluid pressure signal strength will constantly attenuation, the attenuation degree influenced by the signal frequency and transmission distance, also with the drilling fluid channel diameter, drilling fluid type and group, viscosity and volumetric water internal parameters such as gas rate[6]. Therefore, it is important to study the transmission characteristics of the signal in the drill pipe to improve the efficiency of signal transmission and the effective use of the signal energy and the optimization of the drilling fluid information telemetry system.

Because pressure wave is a kind of energy conversion process between kinetic energy and potential energy, the transmission of drilling fluid pressure signal is a kind of energy conversion process [7]. Due to the viscous resistance of the drilling fluid and elastic deformation of the pipeline during the transmission, the pulse signal will be delayed and attenuated [6]. Compared with the length, the radial of the drill pipe is relatively rigid, and the diameter is very small, so the axial direction of the drill string will be used as the transmission channel of the drilling fluid pressure signal. Almost all of the signal energy is transmitted to the drilling fluid in the drill pipe.

A. *The transfer function of the drilling fluid channel*

The pressure signal generated by the drilling fluid pressure generator is transmitted in the drill pipe. When the surrounding environment and fluid circulation are stable, the transfer function of the drilling fluid channel basically does not change with time or change very little. It can be seen as a linear system [8].

The attenuation of the signal amplitude is related to the transmission distance of the signal in the channel and the characteristics of the drilling fluid itself [9,10]. Cartesian based on pipeline pressure wave attenuation of Rambo law [11], puts forward the quantitative relation between the amplitude and the transmission distance attenuation.

$$p(x) = p_0 e^{-x/S} \tag{1}$$

Therefore, the transfer function of the drilling fluid channel is formula 2.

$$H = \frac{p(x)}{p_0} = \exp(-x/S) \tag{2}$$

$$s = \frac{d}{2}\sqrt{\frac{K_1}{\pi fu\left[1+\psi\frac{K_1 d}{E_e}+\beta_s\left(\frac{K_1}{K_g}-1\right)+\beta_s\left(\frac{K_1}{K_s}-1\right)\right]}} \tag{3}$$

$$\psi = \frac{1}{1+\frac{e}{d}}\left[\left(1-\frac{\delta}{2}\right)+2\frac{e}{d}\left(1+\delta\right)\left(1+\frac{e}{d}\right)\right] \tag{4}$$

In the formula 2: P (x) for the transmission of the signal strength after X distance; p_0 for the intensity of signal source; x for transmission distance; S for attenuation factor; β_g for volume fraction of drilling fluid, gas volume flow rate and the ratio of the volume flow rate of each phase[12]; β_s for drilling fluid solid volume concentration; K_g for gas volume elastic modulus;K_1 for liquid bulk elastic modulus; Ks for solid bulk modulus of elasticity; E for elastic modulus of tube; d for diameter of drill pipe; e for wall thickness of drill pipe; δ for the poisson's ratio of pipe; μ for drilling fluid viscosity; f for signal frequency [13].

B. The distribution of the transfer function along the directional well drill pipe

The transfer function of drilling fluid pressure signal is affected by the size and material characteristics, carrier frequency and the characteristics of drilling fluid. The characteristics of the channel (drill pipe and drilling fluid) are analyzed without considering the frequency of the signal [13]. For a fixed signal transmission channel, the dimensions and material properties of the drill pipe are known and remain unchanged. Drilling fluid contained in the solid and liquid components, due to its compressibility is rather low, so solid, liquid bulk elastic modulus K_s,K_1 and solid volume density β_s in drilling column changes extremely weak can regarded as a constant value. The drilling fluid contains the gas part of the high compressibility, the bulk modulus of K_g and the rate of change in the gas rate of β_g under different pressure[13]. Therefore, it is very important to analyze the distribution of the pressure in the drill pipe to study the transmission characteristics of the signal.

Affected by the gas compressibility, the gas volume modulus of elasticity in the transfer function Kg and the gas bearing ratio β_g are related to the pressure of the drill pipe[8]. According to the relationship between the gas elastic modulus and specific heat ratio and the ideal gas state equation, the elastic modulus of the gas volume along the axis i node is

$$K_{gi} = mp_i \tag{5}$$

Where m = 1.2, the gas specific heat ratio. The content of β_g in drilling fluid is related to the volume of gas in the unit volume drilling fluid. The ratio of the ratio of any two nodes in the drill string is actually the ratio of the volume of gas in the unit volume drilling fluid[13]. β_{g0} represents the gas rate of drilling fluid at the wellhead. The volume of gas in the unit volume drilling fluid is 0. When the drilling fluid flows to a node i, the pressure and temperature of the gas contained in the drilling fluid will change. The gas volume at the node i is V_i, and the gas content of drilling fluid is β_{gi}. Each parameter is substituted into the ideal gas equation of state can be obtained the gas content of drilling fluid and the change in the relationship between the volume of gas. The gas content of drilling fluid in the borehole along the axis node i is derived.

$$\beta_{gi} = \beta_{g0} \frac{p(273+T_i)}{p_i(273+T_0)} \tag{6}$$

In the formula 6, P represents the wellhead pressure. T_0 represents the wellhead temperature. p_i represents the pressure of node i. T_i represents the temperature of node i.

III. DRILLING FLUID PULSE MODULATION METHOD

A. Pulse position modulation

Because of the high energy efficiency of pulse position modulation (PPM), it is widely used in the occasions of limited power [13]. PPM was a modulation format that maps message bits to pulse positions. In the modern use of the term, a PPM symbol compresses M slots, exactly one of which contains a pulse. Input message bits determine which of the M positions was used. For the simplest mapping, M was typically taken to be a power of 2, in which case message bits specify one of the M possible positions of the pulse, as shown in Figure 1. If the slots were numbered 0, 1, ⋯, M－1, then in the mapping shown in Figure 3, the decimal representation of the bits was the number of the slot containing the pulse. As shorthand, M-ary PPM was often referred to as M-PPM. Mathematically, M-ary PPM may be described as the encoding of a k-bit source U=(U1 , ⋯, Uk)∈{0,1} k to yield a signal X = (0,⋯,0,1, 1, 0, ⋯, 0)∈{0,1}M, M =2k , which contains a single one in the position indicated by the decimal representation of U.

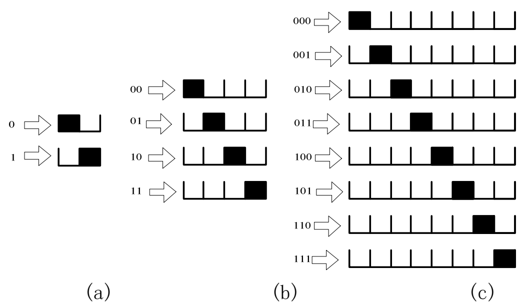

Figure 1. M-ary PPM maps log2M bits to a pulse in one of M positions—(a) binary PPM, (b) 4-ary PPM, (c) 8-ary PPM.

To facilitate the analysis in this paper, we now formalize a description of the system model. The transmission channel for each slot, the slot channel, was a binary-input unconstrained-output channel [8]. This was illustrated in Figure 2.

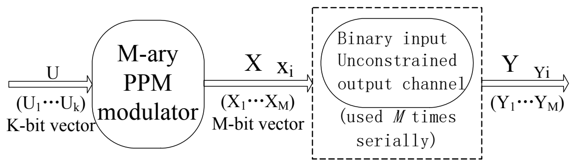

Figure 2. Block diagram of PPM modulator

Input bits were first fed into a linear block product encoder for encoding, which has been mapped into the PPM symbol by the encoding information and converted to drilling fluid pulses emitted out. The product of encoding and symbol mapping constitute a serially concatenated system.

To achieve the downward transfer of the ground command, not only need to be able to produce drilling fluid pressure pulse at the bottom, while the down hole tool must be able to identify the drilling fluid pressure pulse from the analysis of the corresponding control instructions[14,15]. Therefore, the transmission of drilling fluid pressure pulse must be carried out according to a certain rule or time sequence, that is, the signal must be coded accordingly. For the signal transmission system of rotary steering drilling tool, the code must follow the principle of accuracy, timeliness and feasibility.

B. Pulse width modulation

Pulse width modulation wireless remote control communication system to transmit the signal for a series of pulse waveform. The pulse waveform is determined by the transmission protocol, anti-jamming and optimization measures. The high pulse width of a single pulse in the pulse sequence contains data type information, and the low pulse width contains information about data size and coding. Due to the adoption of the "dynamic data transmission" measures, the data sampling and comparison time is adequate. In a cycle, the first step is to send a check pulse, representing the beginning of a new cycle of data pulses. Then the second step is to send the data pulse, the number of data pulses and the number of data types and the number of changes in the number of data domain. Finally, the last step is to send the end of the pulse, on behalf of the cycle to send an end.

C. Pulse interval modulation

Pulse interval modulation is a kind of pulse position modulation similar to PPM, but the number of slots contained in each symbol is changed rather than fixed. The number of slots in the symbol Sk (the decimal number represented by the symbol Sk) is k+2, and the pulse is on the starting time slot of each symbol. It is added a protected space slot and added k time slot representation of information. When the receiving end of the PIM is used for demodulation, the number of empty slots after the pulse slot is only needed after the pulse time slot is judged, and the number of the time slots is reduced by one. Therefore, PIM only needs clock synchronization in the receiver and does not need symbol synchronization, which is greatly simplified compared with PPM in system implementation.

It can be seen that the width and the interval of the pulse signal changes with the modulation signal in a data transmission period after taking the measures of anti-disturbance and parameter optimization. This width and interval contains information about the pulse signal with the PIWM (pulse width modulation) signal has a similar signal. But the width and interval of PIWM pulse signal is corresponding to the value of the modulation signal of the adjacent different sampling points, and the pulse width and interval of the pulse signal contains the modulation signal value and the coding information of the same sampling point.

D. Signal coding mode design

For drilling fluid pressure pulse, the falling edge is fast and easy to be recognized. The signal transmission system of the rotary steering drilling tool is set falling edge as the source of signal coding. In order to receive and recognize the drilling fluid pressure pulse signal in each pulse is required after a certain recovery time. That is to send a pulse after the need to wait for the next recovery cycle in order to carry out the next pulse of the transmission. If the pulse is used to express the digital signal "0", "1", the transmission process requires frequent switching of the ground leakage device; the system has a great impact on the system. In order to simplify the operation, the system has the ability of anti-interference and fault tolerance of digital coding, and the coding mode of information transmission is designed with 5 pulses. The whole command is divided into 4 regions, each of which takes a full pulse as the starting signal. Each region is composed of 4 parts: pulse fall time, pulse recovery time, command time (T1, T2, T3 and T4). The instruction format is shown in Figure 3.

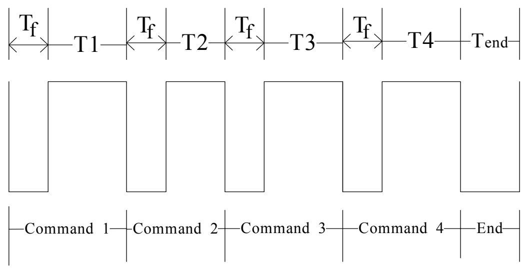

Figure 3. Coding mode of signal transmission system

IV. CONCLUSION

In this paper, the pulse interval and pulse width modulation code and its application in the well trajectory control tool are presented. The PIWM code is made up of discrete pulse width and pulse interval. Its equipment is simple, and no reference to the synchronization signal. Drilling fluid pulse PIWM was a simple and feasible method to realize the steering drilling system downhole signal transmission. The control circuit part of the downhole instruction downhole steering tool in receiving function can be in the downhole tool the corresponding hardware and software implementation. By collecting the data of the downhole mud motor output voltage, the CPU can detect the change of drilling fluid flow. The key to guide drilling system downhole communication software was to achieve input voltage threshold, and the pulse width timing processing. There was more interference in the transmission process in the pulse pressure of drilling fluid drilling site, need to take effective measures to improve the reliability of the transmission of downhole receiving device.

REFERENCES

[1] D.Feng, Y.X.Yuan, H.X.Li and S.Y.Bian, "The status and development trend of trajectory control tool. "China Petroleum Machinery, vol.39, pp.70-73, 2011.

[2] X.S.Liu and Y.N.Su, "Scheme design of downward signaling system."Acta Petrolei Sinica,vol.21,pp.88-92, 2000.

[3] F.F.Li, S.Q.Jiang ,H.X.Li and D.L.Gao, "Study on downward signaling system of rotary steerable drilling tool." China offshore oil and gas,vol.24, pp.42-47, 2012.

[4] Q.J.Yang and J.Li, "A scheme for downward communication in the steerable rotary directional drilling system." Petroleum Geology and Recovery Efficiency, vol.11, pp. 75-77, 2004.

[5] H.Y.Sun, "Technology of magnetic induction transmission of intelligent drill pipe and its channel characteristics." Journal of China University of Petroleum(Edition of Natural Science), vol.37,pp. 172-176, 2013.

[6] S.S.He and X.S.Liu, "Analysis of Signal Attenuation for Positive Drilling Fluid Puls." Drilling & Production Technology, vol.24, pp.1-3, 2001.

[7] X.SH.Liu and Y.N.Su, "Analysis of transmission characteristics of drilling fluid pulse signal." Oil Drilling& Production Technology, vol.22, pp.8-10, 2000.

[8] Y.Shen, Y.N.SU, L.LI and G.SH.LI, "Analysis on transmission characteristics of differential phase shift keying signal of continuous pressure wave in drilling fluid channel. "Acta Petrolei Sinica, vol.30, pp. 593-597 , 2009.

[9] Z.H.Shi and X.SH Liu, "An Analysis of Drilling Information Transmission Behavior in Well bore." Natural Gas Industry, vol.22, pp.68-71,2002.

[10] Grosso D.S., Raynal J.C. and Rader D., "Report on MWD experimental downhole sensors." SPE10058, 1981.

[11] Hutine R., Tenneant R.W., Kashikar S.V., "New Mud Pulse Telemetry Techniques for Deepwater Applications and Improved Real-Time Data Capabilities". SPE/IADC 67762, 2001.

[12] X.SH.Liu and Y.N.Su, "Study on Transmission Velocity of Mud Pulse Signal." Petroleum Drilling Techniques, vol.28, pp. 24-26,2000.

[13] K.X.Luo, "A Research on the Transmission Characteristic of Mud Pulse Signals Generated by MWD System". China University of Petroleum, vol.1, pp.1-46, 2008.

[14] X.Fang, Mohammad-Ali K., Salah B., "Coded PPM and multipulse PPM and iterative detection for free-space optical links." J.Opt.Commun.Netw, vol.1, pp. 404-414, 2009.

[15] D.Chen, X.ZH.Ke, "Analysis on error rate of wireless optical communication using subcarrier modulation on turbo code." Acta Optica Sinica,vol.30,pp. 2860-2863,2010.