ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 15 (2011) 2364 – 2368
Procedia Engineering
www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Continuous-wave mud telemetry digital communication system design and the simulation test

Xinping Liu[a],Xiwen Xue[b],a*

[a]*Xinping Liu,Computer and communication engineering college, China University of Petroleum, Dongying Shandong 257061*
[b]*Xiwen Xue,Computer and communication engineering college, China University of Petroleum, Dongying Shandong 257061*

Abstract

This paper researched on the continuous wave mud telemetry MWD system based on the frequency modulation (FM) transmission mode. The digital communication system based on the continuous wave mud telemetry was designed. The system architecture design includes the ground signal transceiver devices, the bottom signal transceiver devices, as well as the third part of data transmission channel. In the initial stage of the system design, the wind tunnel simulation tests could be employed. The structure of the wind tunnel test model was designed according to the similarity principle, and a series of wind tunnel simulation tests were carried out for data transmission. Test results showed that the continuous wave mud telemetry MWD system based on the FM transmission mode could achieve higher data transfer rate, improve job reliability, and enhance the adaptability to the environment.

Selection and/or peer-review under responsibility of [CEIS 2011]

Keywords: measurement while drilling; continuous-wave mud telemetry; frequency modulation data transmission; data transfer rate; wind tunnel simulation test

1. Introduction

Measurement While Drilling (MWD) is a new well logging technology developed in recent years, which is most widely used drilling mud as the medium in signal transmission technology of MWD system nowadays, but its disadvantage is low transmission rate, poorly anti-interference ability and lead to error

* Xinping Liu. Tel.: 13505469286; fax:0532-86981327.
E-mail address: liuxinp@upc.edu.cn.

doi:10.1016/j.proeng.2011.08.443

easily. The continuous wave mode has high transfer rate and high anti-interference ability comparatively, so it represents the development of wireless MWD data transmission technology[1]. But its maximum transfer rate is only 12 bps which is not ideal. This paper designed the structure of continuous-wave measurement while drilling mud system by using multi-band frequency data transfer mode. By doing some wind tunnel simulation tests some progresses and useful conclusions have been made.

2. The Digital Communications of Frequency Modulation

The existed continuous wave signal generators made by Schlumberger use binary phase shift keying digital modulation mode, which generate the fixed frequency continuous pressure wave by a two-phase synchronous motor. So we can get 180° phase by changing the instantaneous speed of the motor. Therefore phase 0° corresponds to the binary "0",while 180° corresponds to the binary "1". It is a very complex communication system because of high requirements in the timing synchronization, controlling motor and enforcement agencies, so these shortcomings limit the widespread application.

Here is a formula about the relationship between information transmission rate and code transmission rate:

$$R_B=R_b/log_2^M(B) \quad (1)$$

Where R_b is information transmission rate, R_B is code transmission rate, and M is decimal numbers. We can get a conclusion that information transmission rate R_b is increased by adding the number of decimal digits M in the case of R_B unchanged, so ary digital modulation system can replace binary digital modulation to transmit down-hole information.

The continuous wave signal generator which is based on binary phase shift keying method has lower bit error rates (BER). But the multi-ary phase modulation could produce phase ambiguity problem easily[2]. Compared with MASK and MPSK, the BER in MFSK is increased slightly. Meanwhile, MFSK has a better ability to adapt in the parameter channel. In addition, the sending and receiving device of multi-ary phase modulation is much more complex than the multi-band frequency modulation.

By the above analysis, this paper adopted multi-band digital frequency modulation to transport the underground information, and binary, quaternary, octal were used to enhance the adaptability of the environment. The transmission time of each symbol was set to 0.2s and 0.3s respectively. According to the different combinations of the number of M and the binary symbol transmission time, 6 kinds of data transfer modes were set：DM1—DM6，which were shown in the table 1:

Table 1. Data transmission mode and parameters Table 1

Transfer mode	Encoding mode	Number of bits / symbol	Symbol transfer time	Minimum carrier frequency	Maximum carrier frequency	Data transfer rate(bit/s)
DM1	Binary	1	0.3s	15Hz	20Hz	3.3
DM2	Binary	1	0.2s	20Hz	25Hz	5
DM3	Quaternary	2	0.3s	15Hz	24Hz	6.7
DM4	Quaternary	2	0.2s	15Hz	24Hz	10
DM5	Octal	3	0.3s	15Hz	36Hz	10
DM6	Octal	3	0.2s	15Hz	36Hz	15

The experimental data and related algorithms[3] were used to predict the data receive error rate in different transmission mode, so as to select the best transmission mode for sending and receiving data.

3. The architecture design of MWD continuous wave mud system

General design of MWD continuous wave mud system is shown in figure 1, mainly includes terrestrial signal transceiver device, bottom signal transceiver device and data transmission channel. The information from down-hole could upload to the ground from data transmission channel.

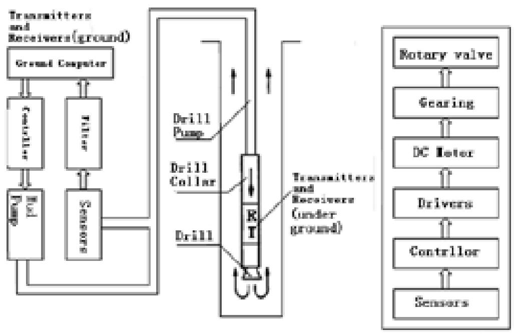

Figure 1. The overall structure of the continuous-wave mud telemetry MWD system

Ground signal transmitters and receivers include the ground floor reception and signal transmission module which are separated from each other, they are controlled by ground computer. The ground system mainly receives all the information uploaded from the bottom when data received correctly. The pressure sensor which is located in the mud standpipe detects the pressure change in the tube, and coverts the hydraulic wave signal to the analog voltage signal. After amplification, signal will be sent into the programmed ground computer in sequence, and then recover the information uploaded from the mine. The ground computer can find the optimal ways by the conditions of wells, and change the down-hole data transmission by instructions.

The bottom signal transfer device includes signal generator and bottom signal receiver. The signal generator is composed by controllers, drives, DC motor, gear instrument, and rotary valve. The controller based on the digital signal processor (DSP) could control the rotation of the rotor in the rotary valve by controlling the operation of DC motor. The rotary valve is composed by the rotor and the stator with holes. In the rotating process, the rotor and the stator could cut the fluid to generate different pressure, so the pressure fluctuation signals[5] are obtained. The down-hole signal receiver is composed by pressure sensor and controller. After receiving the commands sent by ground computer through the sensors, down-hole controller could transmit data to control signal generator by the corresponding data transfer modes and data transfer sequences.

4. Wind Tunnel Simulation Experiment

4.1. Principles of wind tunnel test

The principle of wind tunnel test is the similarity principle. The steady low-speed wind tunnel test(wind speed <100 m/s) only require to simulate Reynolds number (Re) [6].

As an example: we produced a continuous wave signal generator model in the ratio of 1:1 to simulate down-hole mud continuous wave signal generator. Simulation test was arranged under the condition that inner diameter was 126mm, length was 1000mm and under the condition of 25□. Given: ρ(the density of drilling fluid)=1500kg/m3, v(the rate of mud flow)=Q/S=2.4m/s, μ(dynamic viscosity of the mud)=1cP,

ρ_m(air density)=1.185kg/m3, μ_m(air dynamic viscosity)=0.0185cP, and l=lm, if adopted the same Reynolds number, namely:

$$\rho vl/\mu=\rho mvmlm/\mu m \quad (3)$$

Assigned the above parameters into the formula (3), the flow rate of air was calculated in wind tunnel test, v_m=56.2m/s.

4.2. *Wind tunnel simulation experiment*

The structure of wind tunnel test model mainly includes the wind tunnel motor, inverter power system, wind tunnel contract section, wind tunnel test section, gas export terminal, data acquisition and processing system etc. There are several measure hole opened on the test section, which send the gas pressure in the test section to the data capture box via hose. Each point's pressure can be collected by the data acquisition system, then entered into the computer and do the final analysis and treatment by computer.

4.2.1. The test of determining the symbol of transfer frequency

By analyzing the literature [4], 15Hz and 36Hz are selected as the transmission frequency. The symbol differences between the minimum frequencies were determined by the wind tunnel test. The DSP controlled signal generator to produce continuous pressure wave, different frequency signal indicated different symbol information. A fixed 15Hz was set as the starting flag, then sent "1010···" continuously, each group sent 500 bits. The minimum symbol transmission carrier frequency was set to 15Hz, which indicated binary "0". Set the minimum difference of the transmission symbol frequency as 2Hz, 3Hz, 4Hz, 5Hz, which separately used 17Hz, 18Hz, 19Hz, and 20Hz to indicate binary information "1". Set T (the single symbol transmission time) as 0.2s. The data acquisition system collected the data while the signal generator sending the messages, and saved the data after collecting a set of data completely. The experiment result showed that if the minimum frequency of different symbol was 3Hz, the data error rate of receiver was less than 2 ‰ that could be considered as decoder correctly. If the minimum frequency deviation was 2Hz, the error rate increased to more than 5%, which was considered as not decoder correctly. Therefore, the minimum frequencies between the different symbols were determined as 3Hz, so the data could be transmitted by using octal digital frequency modulation system between 15Hz and 36Hz.

4.2.2. Determining the gap of rotary valve tests

The frequency of the wind tunnel was set to 40Hz(flow area were changed with the rotor rotation period), wind speed was varied between 2m/s and 12m/s. Fan-shaped rotary valve was rotated at a fixed frequency which was driven by DC motor. The frequency of pressure wave was 21Hz, and the gap between the stator and rotor was set to 2mm, and 16mm, wind tunnel data acquisition system was used to sample and store them. By comparing all different gaps' pressure response curve of rotary valve, it showed that the smaller gap between the stator and rotor, the bigger, and on the contrary, the bigger gap between the stator and rotor, the less pressure amplitude generated by them. The pressure wave signal could not be transmitted to the ground when the gap was too large.

The output torque of DC motor was not easy to be measured directly, while the output power was easy to be calculated by measuring average output current and voltage. The output power of the motor was proportional to the size of torque in the case of the same speed, so the motor torque could be measured by using output power. In the above rotary valve, the motor currents were measured to be 0.40A, 0.20A respectively, and the rated voltage of motor was 24V, so the output power of the motor could be calculated as 9.6W, 4.8W respectively. It could be seen from the experimental data, the torque were increased when the gap decreased, which was related to the rotary valve closely. But when the rotary valve gap increased to a certain distance, there was no significant change of the torque.

4.2.3. The impact of pressure waveform caused by valve port shape

The frequency of fan inverter was 30Hz, and the pressure wave frequency generated by the rotor rotation which was driven by DC motor was 20Hz. It could be obtained that the pressure wave generated by circular valve port of the rotary valve was closer to the sine wave, while the pressure wave generated by the fan-shaped valve port of the rotary contained other resonant wave. According to spectral analysis theory, the sine wave signal is most concentrated energy spectrum, so the continuous sine wave signal can propagate farther than the other signal. Therefore, the circular valve port is better than valve port sector seen from the resulting pressure wave shape. In addition, the fan-shaped valve port rotary valve area was less than the minimum flow valve port circular, the pressure amplitude generated by the fan-shaped valve port was greater than the pressure generated by circular valve port under the condition of the same wind speed and the same wave frequency. These laws have the guiding significance to the design of the signal generator and smart filtering algorithms when receipt the signals.

5. Conclusions

In this paper, the structures of continuous wave of MWD were designed by using FM multi-band data transmission mode, and carried out a series of wind tunnel data simulation test. The following conclusions were obtained:

(1) The frequency range of symbol transmission was selected between 15Hz and 36Hz, the minimum frequency margin between different symbols was 3Hz. Octal frequency modulation was the maximum usable to transmit data. The minimum transfer time for each symbol was set to 0.2s, so that maximum data transfer rate could attained to15*bps*. Compared with binary phase modulation, the Octal frequency modulation meld could achieve higher data transfer rate.

(2) The type and change regularity of pressure fluctuation signal depend on the valve port shape and the movement of rotary valve. The pressure wave generated by circular valve port of the rotary valve is closer to the sine wave than generated by the fan-shaped valve port, which is beneficial to the signal transmission.

(3) Wind tunnel test can simulate experiment under the condition of flow media without current gas. By the wind tunnel simulation experiment, the test efficiency could be increased, and the testing cost could be reduced. In these ways the MWD system development cycles should be shortened.

Acknowledgments

The authors gratefully acknowledge the natural science foundation of Shandong Province and the special funds of Chinese colleges for basic scientific research projects.

References

[1] SU Yinao, DOU Xiurong. Measurement While Drilling, Logging While Drilling and Logging Instrument[J]. Oil Drilling& Production Technology, 2005，27（1）: 74-78.

[2] ZHANG Hui, CAO Lina. Communication Theory [M]. Beijing: Science Press, 2007.

[3] LIU Xinping, TANG Lei, JIN Youhai. Extending hidden-layer backpropagation neural network and its' training algorithm [J]. Computer Integrated Manufacturing Systems, 2008,14(11):2284-2288.

[4] R.Hutin, R.W.Tennent,S.V.Kashikar. New Mud Pulse Telemetry Techniques for Deepwater Applications and Improved Real-Time Data Capabilities[C]. SPE/IADC Drilling Conference, Amsterdam, The Netherlands, U.S.A 2001-2-27.

[5] Wilson C.Chin. Measurement-while-drilling system and method:U.S.Patent,5583827 [P]. 1996-12-10.

[6] WANG Tiecheng. Aerodynamic test technique [M]. Beijing: Aviation Industry Press, 1995.