PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 40, Issue 2, April 2013
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2013, 40(2): 242–248.

RESEARCH PAPER

Electromagnetic measurement while drilling technology based on the carrier communication principle

SU Yi[1,*], QI Xin[1], LIU Yang[1], ZHANG Jinguang[2]

1. School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China;
2. Geological Department, Shanxi lu'an Environmental Energy Development Co.Ltd, Changzhi 046204, China

Abstract: To improve data transfer rate and signal telemetry depth in electromagnetic measurement while drilling (EM-MWD), and to solve the problems of short life expectancy and poor reliability of drill pipes as well as serious electromagnetic scattering, this paper presents the measurement while drilling (MWD) method based on the carrier communication principle. Based on carrier technology, the electromagnetic wave signal was coupled with the drill pipe through the coupling transformer, where the drill pipe and formation can form the guiding wave system to achieve data transfer between the ground and the bottom. The transmission line equation is developed based on the analysis of the transmission characteristics of electromagnetic waves in strata and drill pipes, and the overall structure of the system is presented. The real transmitter and receiver are produced by using LM1893 as the carrier module. In addition, the system optimization is proposed. The electromagnetic waves loaded on the drill pipe using carrier technology can transmit drilling measurement parameters from the bottom to the surface in real time, and send setting parameters and commands from the surface to the bottom simultaneously through the drill pipe-formation channel, and thus achieve the implementation of bi-directional communication between the ground and the bottom.

Key words: EM-MWD; through-the-earth communication; carrier communication; data transmission

Introduction

In the petroleum and natural gas drilling and coal mining projects, measurement signals need to be transmitted from the bottom to the ground in real time. These signals mainly include rock physical identification signals such as formation fluids, lithology and reservoir physical properties as well as engineering parameter signals such as the direction, position, trajectory and tool face angle of the drill bit. The signal acquisition is mainly achieved by various measuring sensors mounted on the drill bit, while the signal transmission is realized through the technology of MWD (Measurement While Drilling) [1–3], in which the drill pipe is filled with drilling fluid and the mechanical pulse wave generated by the wave generator is transmitted through the drilling fluid. However, in this way the data transmission speed is low, the system structure is complex and it only applies to gas-free pure liquid drilling. In recent years, with the development of drilling technology, underbalanced drilling and air drilling technologies have come about one after the other [4], so Russia and the United States have begun the study on the technology of electromagnetic measurement while drilling (EM-MWD) that uses electromagnetic waves to transmit data from the bottom to the ground through the strata. The main bottleneck of this technology is that the formation conductivity which is too high or too low will have adverse effect on the electromagnetic wave propagation depth [5–6]. In addition, products of this technology are expensive, and the United States and Russia blockade this technology, therefore, the relevant theories and experiments are rarely seen in China [7].

Since its advent in the 20th century, carrier technology has been rather mature in common wired and wireless carrier communication. However, new problems have to be solved when applying it to the field of MWD because it is not a single wired communication. In this paper, the electromagnetic wave signal is applied to the drill pipe by using carrier technology and transmitted to the ground through the channel composed of the drill pipe and formation to implement the bi-directional communication between the ground and the bottom.

1 Signal transmission principle of the EM-MWD system

EM-MWD usually adopts a truncated drill pipe with an insulating joint connecting the upper and lower sections of the

Received date: 13 Mar. 2011; **Revised date:** 29 Jan. 2013.
*** Corresponding author.** E-mail: suyee830916@163.com
Foundation item: Supported by the Basic Research Funds Reserved to State-run Universities (FRF-TP-12-059A).

drill pipe, forming an asymmetry dipole antenna to transmit electromagnetic wave. The disadvantages are as follows: on the one hand, the insulation segment has to withstand huge torque and pressure, thereby greatly reducing the reliability and life of the drill pipe; on the other hand, in order to enhance the penetrating ability of electromagnetic wave through the formation, the transmission frequency of the electromagnetic wave is very low, usually 10 to 30 Hz, so it is difficult to obtain a high data transmission speed. In addition, when using the drill pipe to emit electromagnetic wave, it radiates toward all directions and the energy is not concentrated so the signal in receiving point is very weak, affecting transmission depth greatly. In view of problems mentioned above, in order to ensure the reliability and service life of the drill pipe, and increase the transmission distance, the power line carrier communication principle can be used to transmit high frequency electromagnetic wave to the receiving point through the guide of the drill pipe, which not only reduces the electromagnetic wave radiation loss, but also improves the data transmission speed.

1.1 Power line carrier communication principle

The principle of power line carrier system is shown in Fig.1. The most important issue in using power line carrier communication is how the high frequency signal is coupled to the power line. The phase-earth coupling mode is commonly used, in which a high-pass filter is constituted by a coupling capacitor and a combination filter, letting high-frequency signal pass smoothly, to achieve the purpose of coupling the high-frequency signal to a power line. The wave trap is a tuned circuit, whose inductance coil is a strong flow coil which lets 50 Hz current pass by, and the entire tuning circuit resonates in the vicinity of the high-frequency signal frequency, to prevent the high-frequency signal flowing through, and bypass effects of the power plant or substation bus on the high-frequency signal.

1.2 EM-MWD system based on carrier technology

In drilling, rotating drill pipe is used in general to drive the drill bit to realize the steerable drilling. The drill pipe commonly made of ultra-high-strength steel, has excellent conductive properties. Based on the power line carrier communication principle, the drill pipe can be equivalent to a power line, which can be used as the transmission channel of the carrier signal to form EM-MWD system (Fig. 2). The EM-MWD system consists of a downhole transmitter and a ground receiver. The downhole device is installed within the non-magnetic drill collar and various sensors mounted in it detect downhole parameters such as temperature, pressure, drilling tool attitude angle, reservoir physical property, natural gamma ray etc. These parameters will be modulated into a certain frequency electromagnetic wave, which will be loaded onto the drill pipe through the phase-earth coupling after filtering and amplifying. Then the electromagnetic signal will be transmitted to the ground through the channel composed of the drill pipe and the earth. The receiver receives data from the bottom and displays them on the host computer after filtering and demodulating so that the driller can understand the situation in the bottom and control the drilling trajectory.

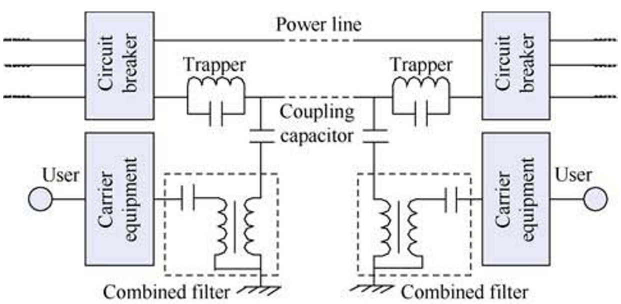

Fig. 1 Block diagram of power line carrier system

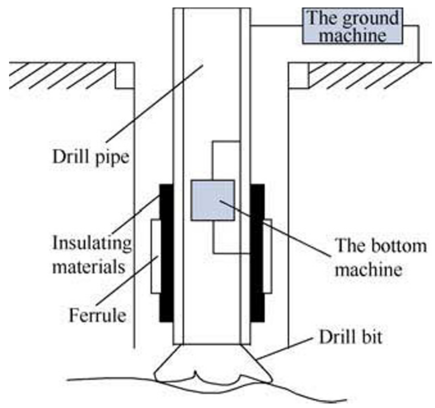

Fig. 2 Constitution of the EM-MWD system

2 Analysis of electromagnetic wave transmission

2.1 The transmission characteristics of electromagnetic waves in formation

In electromagnetic communication through strata, the main factors affecting the propagation of electromagnetic waves are the electromagnetic parameters of the earth, including conductivity, magnetic permeability and permittivity. The three parameters jointly affect the propagation of electromagnetic waves in the formation and the propagation coefficient can be expressed as follows:

$$k = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} = j\omega\sqrt{\mu(\varepsilon - j\sigma/\omega)} = \alpha + j\beta \tag{1}$$

where,

$$\alpha = \omega\left\{\frac{\mu\varepsilon}{2}\left[-1+\sqrt{1+(\sigma/\omega\varepsilon)^2}\right]\right\}^{1/2}$$

$$\beta = \omega\left\{\frac{\mu\varepsilon}{2}\left[1+\sqrt{1+(\sigma/\omega\varepsilon)^2}\right]\right\}^{1/2}$$

When $|E/E_0| = 1/\mathrm{e}$, we can get the skin depth:

$$\delta = 1/\alpha = \sqrt{2}/\left\{\omega^2\mu\varepsilon\left[-1+\sqrt{1+(\sigma/\omega\varepsilon)^2}\right]\right\}^{1/2} \tag{2}$$

Because the magnetic permeability in the formation and the free space is the same, the propagation coefficient in the formation can be written as: