TELKOMNIKA, Vol. 11, No. 12, December 2013, pp. 7509~7515
e-ISSN: 2087-278X

The Research of Through-casing Resistivity Logging Calibration System Leakage Current Measurement Method

Zhang Jiatian*[1], Wang Huanyou[1], Bao Dezhou[2]
[1]Key Laboratory of Education Ministry for Photoelectric Logging and Detecting of Detecting of Oil and Gas, Xi'an Shiyou University, Xi'an, Shaanxi, China
[2]China Petroleum Logging CO. LTD., Xi'an, Shaanxi, China
*Corresponding author, e-mail: 354929582@qq.com

Abstract

This paper introduces the logging principle of through-casing resistivity logging technology, finds a phenomenon that the leakage current measurements are susceptible to sufferring interferences. The through-casing resistivity logging technology in Russia and that of Schlumberger are studied, and the system of through-casing resistivity logging is established to improve the accuracy of calibrating, testing and measuring of the instrument. In this paper, distribution parameters of the form is replaced by the lumped parameter, and precision resistor array simulation in formation leakage current and scale pool simulation in different resistivity of formation are conducted, which make the dynamic range of the simulation in formation resistivity of the medium increase to 1-300 $\Omega \cdot m$ and meet the requirement of through-casing resistivity logging technology measurement range, $1\Omega \cdot m$~$100\ \Omega \cdot m$. Since the measuring signals of calibration acquisition and processing systems are extremely weak and calculation signals need to tell the nV (nanovolts) level, the high accurate data acquisition system of 24 digits is applied.

Keywords: *through-casing logging, calibration system, leakage current, formation resistivity and acquisition system*

1. Introduction

Through-casing resistivity logging technology [1-2] is one of the high and new technologies that are studying in China. Through-casing resistivity logging tool in Russia and CHFR [3-5] Schlumberger are maturical technology developments at home and abroad, which are determined by measuring the voltage drop on the steel casing so as to measure formation resistivity. But useful acquisition signals in the nV voltage are vulnerable to all kinds of interferences [6-8], thus we establish the calibration system [9-10] to indirectly measure leakage current and reduce the errors. Through-casing resistivity logging calibration system provides instrument calibration, testing of test platform, and instrument performance testing and the accuracy of measurement standards, realizes the inspection of instrument accuracy and optimizes performance index parameters based on the analysis of the casing resistivity logging method. The precise measurement of the leakage current, acquisition and processing and different stratum medium simulation by scale pool [11] are the key skills in study of through-casing resistivity logging technology

2. Logging Principle of Through-casing Resistivity Logging Technology

The resistivity of metal casing are much lower than the formation resistivity, so most of the currents flow in the metal casing, but there is still a very small part of the current that leak into the ground through the metal casing. We can get information of formation resistivity by detecting the leakage current.

Received June 27, 2013; Revised August 10, 2013; Accepted August 31, 2013

Simply, the principle of through casing resistivity logging is in the casing by measuring the voltage drop on the casing so as to measure the formation resistivity. As shown in figure 1, if there is a current injected casing, most of the current to flow along the casing will be up or down, and only a small part of thecurrent leaks into the surrounding formation. If we can measure the leaking current on the length in △Z range and voltage V in the middle of △Z, the visual resistivity can be calculated, the formula is as follows:

$$\rho_a = k \cdot \Delta z \frac{V_0}{\Delta I}$$

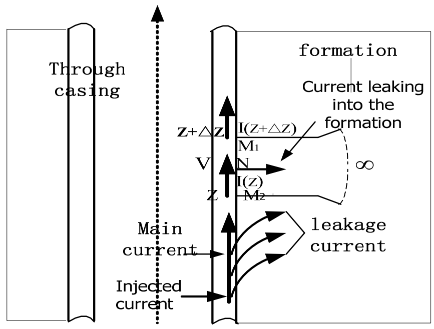


Figure 1. Principle of through Casing Resistivity Logging

Where:

K - The instrument constants;

V - Reference potential of electrodes;

Δ I - Leakage current to ground.

Magnitude of Voltage V is easy to measure precisely, so the precision of the resistivity mainly depends on the leakage current. Then we mainly discuss how to get accurate calibration system leakage current value.

3. Casing Resistivity Logging Calibration System Configuration

This paper uses TMS320F2812DSP [12] as main control chip to design calibration system as shown in Figure 2, the system can achieve acquisition and processing of the weak voltage signal on the casing, and transfer processed data to the total data transmission control module, then data transmission control module transmits data to the PC again.

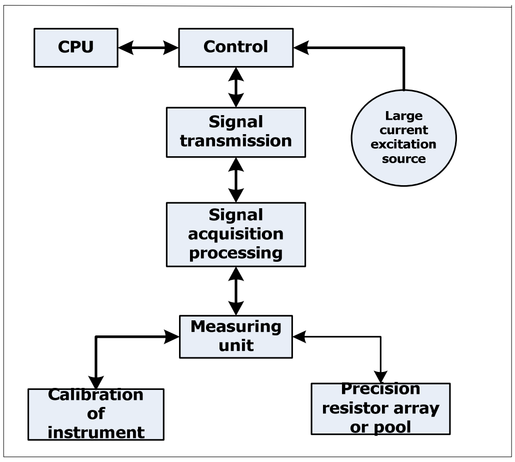


Figure 2. Calibration System Configuration

Through-casing resistivity logging calibration system simulates well logging process of through-casing resistivity logging tool, which include simulating the true casing environment, the different stratigraphic media leakage current conditions, test of different medium environments and data acquisition and data processing ability of casing logging instrument. Through-casing resistivity logging calibration system is mainly composed of signal conditioning, signal acquisition, signal processing, control system, signal transmission, stratigraphic medium simulator and the precision resistor array or pool, etc. Precision resistor array is used to simulate formation leakage current, and scale pool is used to simulate the formation resistivity.

4. The Study Method of Leakage Current Measurement

Principle of through-casing resistivity logging in Schlumberger is first to inject extremely low frequency electric current into steel casing wall, then measure the formation resistivity by measuring the voltage drop on the casing.

$$R = K \cdot \Delta Z \frac{U(z)}{\Delta I} \tag{1}$$

$$\Delta I = S_{casing} \cdot \Delta V / \Delta Z \tag{2}$$

Where:

△Z-The distance between the adjacent two electrodes;
△V-The voltage difference between two points Z apart;
S_{casing} - The conductance of the unit length of the casing;
△I- The casing leak current into the formation from Z length;
R - Formation apparent resistivity.

When formation resistivity that surrounds the wellbore is not evenly distributed, the apparent resistivity of formation can be measured.

Russian Logging instrument of mainly consists of two power supply electrodes, three measuring electrode and electronic circuit. The two power supply electrodes work by turns. There are three measuring electrodes to measure formation current, potential and second order potential difference, then the resistivity of formation is obtained.

$$R_a = k \cdot \frac{U(I_1)\Delta U_{M_1M_2}(I_2) - U(I_2)\Delta U_{M_1M_2}(I_1)}{-\Delta^2 U(I_2)\Delta U_{M_1M_2}(I_1) + \Delta^2 U(I_1)\Delta U_{M_1M_2}(I_2)} \times \left[\frac{\Delta^2 U(I_1) - \Delta U_{M_1M_2}(I_1)}{I_1} + \frac{\Delta^2 U(I_2) - \Delta U_{M_1M_2}(I_2)}{I_2}\right] \tag{3}$$

Where:

R_a- Apparent resistivity of the formation;
K - Instrument constants;
U_{M1} - M_1 point of the potential;
U_{M2} - M_2 point of the potential;
U_N - N point of the potential;
△U_{M1M2} - Potential between M_1 and M_2.

Resistivity calibration coefficients are given by inspecting measuring ability of the casing resistivity logging tool in simulation of the actual conditions of formation resistivity solution in the pool, and then instrument's final calibration coefficient is got combined with leakage current calibration coefficient. Based on the above analysis, the quantity traceability system of through-casing resistivity logging tool is shown in Figure 3.

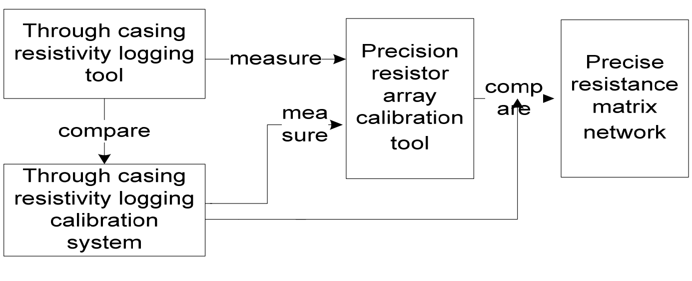
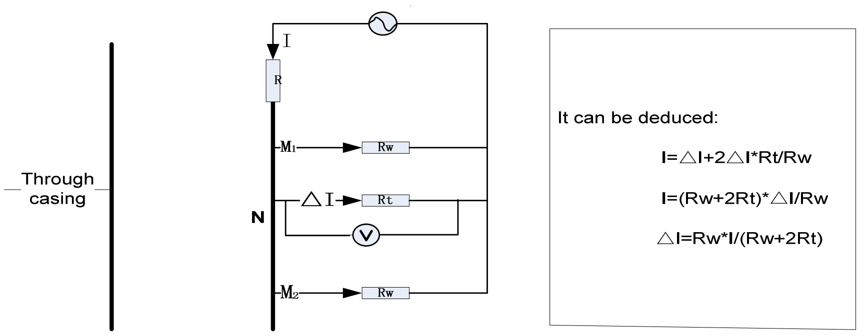


Figure 3. The Quantity Traceability System of Through-casing Resistivity Logging Tool

4.1. Calculation of Formation Leakage Current by Precision Resistor Array

According to through-casing resistivity logging principle, by apparent resistance measurement accuracy of the formation mainly depends on leakage current ΔI measurement accuracy of the formation, so the scale coefficient is determined by dual calibration of leakage current and the resistivity calculated by leakage current.It is different from general logging tool: We don't directly measure leakage current by pressure drop on the casing, but choose a known standard resistance Rt(1~300Ω resistor assembly is used, a conversion relation existing between the formation resistivity and calibration resistor due to the difference of the electrode system length). A constant current source is added to the ground, and by adjusting the current source leakage current size is measured. System model is shown in Figure 4.



(a) (b)

Figure 4. Precision Resistor Array Model

Where:

Rw - Surrounding rock resistance;
Rt- Strata isible resistance;
R - Casing resistance;
I - Ground excitation current;
ΔI - Leakage current of formation

Engineering operation lumped parameter is applied instead of distribution parameters in practice and the casing resistance between each electrode is calculated as a whole, thus leakage current calibration model is set up as shown in Figure 4(a). Formula in Figure 4(b) is the theoretical calibration standard, we can use the node method to calculate the corresponding equation about leakage current; For the calculation of leakage current, it is necessary to identify nV level and be susceptible to interference, so standard resistance Rt is chosen (1~300Ω resistor assembly being used to the difference of the length of the electrode system, calibration resistor with a conversion relation between the formation resistivity) plus a precise voltage meter to indirectly measure the leakage current. Then compared theoretical value with the calculation value, the scale coefficient is obtained.

4.2. Improvement of the Precision Resistor Array

A certain resistivity of strata leakage current is simulated by putting precision resistor array outside the casing in parallel manner so as to realize the calibration of leakage current and ensure leakage current accuracy of the logging instrument.Through-casing resistivity logging in the casing voltage is higher between tens to hundreds of millivolt so we can get high accuracy of measurement. Comparing Figure 4 with Figure 5, we can find:

(1) There is no upper part of the surrounding rock resistance in Figure 5;

(2) Function equation between the I and the leakage current is obtained by using the method of node, the difference of function equation is the coefficient of Rt, which illustrate that the voltage on the Rt in Figure 4 is twice that in Figure 5 under the condition of the same leakage current, increasing power supply current of the large current source and power requirements

Theoretical analysis and calculation show that the model of Figure 5 is better than that of Figure 4.

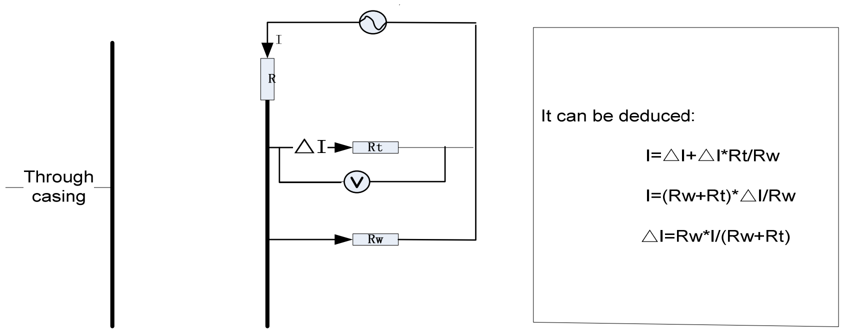


Figure 5. Improvement Model of the Precision Resistor Array

4.3. The Simulation of the Different Resistivity of Formation in Scale Pool

In order to simulate the casing logging environment and process, we can use aqueous solution of different resistivity to simulate different formation medium in scale pool, which makes it possible that the calibration system and the logging instrument measure the casing resistivity of different water solution. Scale pool is designed in Figure 6 and the design measurement range is from 1Ω·m to 100Ω·m, so the corresponding dynamic range of the resistivity of formation medium is 1Ω·m~300Ω·m. The designed task is accomplished by reverse osmosis equipment.

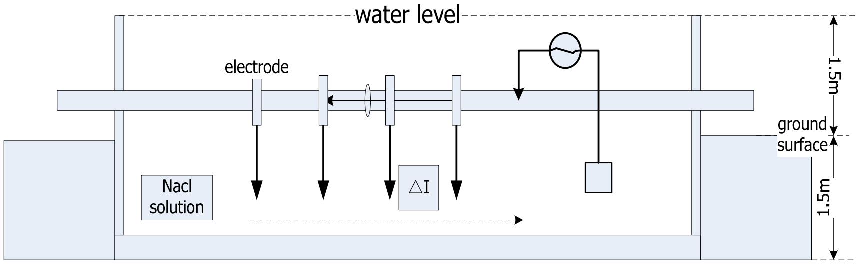


Figure 6. Scale Pool Design

Because water contains trace ions and the conductivity is higher, the electrical conductivity of the tap water range in different areas is about (125~1250)us/cm, that is converted to formation electrical conductivity which is 80Ω·m highest and unable to control, we need reverse osmosis equipment to desalinate water so as to improve the resistivity of water and make treated water reach the kΩ·m level. In the casing, the instrument can calibrate through-casing resistance, measure formation leakage current and simulate the true conditions.

(1) The calibration of scale board corresponding different stratum medium

a) Test the calibration system, draw a calibration board;

b) Test calibration instrument, draw a texting board;

c) Corresponding instrument board, instrument calibration coefficient is obtained by calibrating system board calibration.

(2) Calibration of corresponding different media (more than three)

a) Three different kinds of media are Injectied into a pool;

b) Calibration system tests three kinds of medium;

c) Calibrated instrument tests three kinds of medium;

d) The instrument coefficient is obtained by comparing test results with system test results.

(3) A comprehensive analysis of the coefficient in (1) and (2) is made and eventual coefficient of calibration instrument is got.

5. Acquisition System Design

The right components are chosen by studying weak signal (in the process of casing logging weak signal) acquisition technology and the signal characteristics, and gathering requirements, then design the flow chart of Figure 7, analog and digital circuit and debugging are completed. Acquisition system mainly includes 24-bits Δ -∑ADC digital-to-analog converter [13-14] and DSP control.

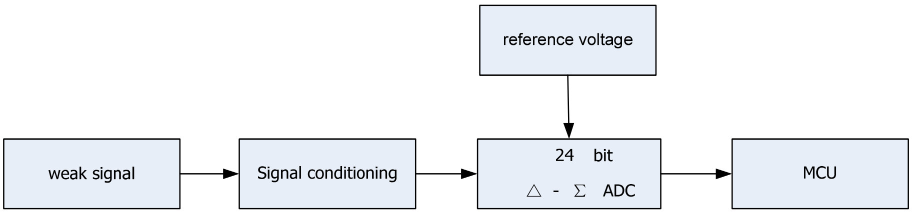


Figure 7. Acquisition System Design

Weak signal is magnified and regulated by single-ended difference modulating circuit, after that, digital to analog conversion is adopted in the first place. Traditional digital-to-analog converter includes parallel type, successive approximation type, integrating type and Δ -∑ type that has developed in recent years. 24-bits Δ -∑ ADC1274 adopts extremely low quantizer to avoid the difficulty of marking high converter and the high precision resistor network. On the other hand, the Δ -∑ modulation technology and digital sampling filter are adopted, which can achieve very high resolution, and are not sensitive to amplitude change of sampling values. Meanwhile, there are automatic calibration and system calibration in it to reduce the errors. Therefore, we choose TI's multi-channel 24-bits industrial analog-to-digital converter.

6. Analysis of Test

TMS320F2812DSP was used as core chip to develop and manufacture the casing resistivity logging calibration system, realize the precise calibration of instruments and completing the collection and processing of weak signal. Formation resistivity value was calculated according to the test of leakage current, and the system test was carried on. The experimental results showed that the formation resistivity measurement can reach 100 Ω·m, measuring precision met the design requirements, and the whole system worked stably.

7. Conclusion

In order to ensure the measurment parameters accuracy of the oil well logging instrument and maintain the unity of the value system, the logging instrument must be calibrated, for logging device without calibration is not credible.

The calibration of casing logging tool should firstly investigate, for the ability of leakage current measuring represents that of logging. Leakage current measurements need that casing tool can distinguish very weak signal in nV level, it is very difficult in the underground environment, the accuracy of leakage current is directly related to the calculation of formation resistivity, so we need precision resistor array to simulate leakage current of a certain resistivity formation to realize leakage current calibration of the casing logging tool in order to ensure the detection accuracy of the leakage current.

For each of the downhole instrument calibration of high value and low value, a certain precision scop is required. Beyond this range, then fault may occurs.

Acknowledgement

This work was supported by the National key special projects Program of China (Grant No. 2011ZX05020-004-05). Through casing resistivity logging tool calibration detection

device, Key Laboratory of Education Ministry for Photoelectric Logging and Detecting of Detecting of Oil and Gas, Xi'an Shiyou University, Xi'an, Shaanxi, China;

References

[1] Tian Yongqing, Cased-hole resistivity logging technology. *Special oil and gas reservoirs*. 2003: 10(6).
[2] LI Tingjun, Yang, Haining, Zhao, Qing, Zhou, Zheng-Ou. Development of a single-borehole radar for well logging. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(8): 1985-1991.
[3] LI Jian, Sun Jianmeng, Wang Zhengkai. Russia through casing resistivity logging technology application research. *World Well Logging Technology*. 2012; 36(1): 63-67.
[4] Li Chunhong, Wang Shaohe, Li Dani. The application of CHFR logging technology. *Special oil and gas reservoirs*. 2006; 13(3): 35~37.
[5] Xu Yanliang, Liu, Xiquan. Development of tubular linear permanent magnet synchronous motor used in oil-well field. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2011; 9(3): 515-522.
[6] Kaufman AA. Influence of inductive effect on measurements of resistivity through casing. Geophysics. 1996; 61.
[7] YAN Zhenguo, Zhang Jiatian. Error Analysis of Weak Signal Detection in Cased Hole Formation Resistivity Logging. *World Well Logging Technology*. 2007: 31(5): 486-488.
[8] Zhang Kelai, Zhu Haiming.Weak signal detection technology. *World Well Logging Technology.* 2009; 30(6).
[9] Li Jingqiang. Through casing resistivity logging tool calibration system and the measuring range ground for analysis. *World Well Logging Technology*. 2012; 3: 61~63.
[10] Zheng Lu, Zhang Jiatian. The study of the cased hole formation resistivity logging calibration system. Master, Xi 'an China, Xi'an Shiyou University. 2010-6-24.
[11] LI Guodong, Han Zhexi. The calibration technology Research of through Casing Resistvity Logging. Master, Xi 'an China, Xi'an Shiyou University, 2010-6-24.
[12] Wang Zhongyong, Chen Shiqing. TMS320F2812DSP principle and application technology [M]. Bei Jing: Electronic industry press. 2012.6.
[13] Texas Instrument. ADS1274/1278 Quad/Octal, Simultaneous Sampling, 24-Bit Analog-to-Digital Converters, The document name: SBAS367F, 2011.2.
[14] Wang Huaixiu, Zhu Guowei. High performance, 24-bit analog-to-digital converter ADS1274/ADS1278 and its application. *International Electronic Element*. 2008; (05): 53~56.