Research on Small Signal Amplification Circuit of Downhole Instrument

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***Abstract*—In order to acquire the real-time work of underground drill, promote the security and the reliability, it is necessary to effectively measure the drilling engineering parameter of drilling pressure, torque and side pressure etc. It uses the resistance strain sensor as a converter. The microvolt signal amplifier circuit is designed through analyzing the output signal of the resistance strain sensor. The design is applied with high-precision and rail-to-rail OP AD8552 as the core chip in the microvolt signal amplifier circuit. Through experimental test, it is obtained with experimental data of amplifier circuit. Moreover, the data are processed and analyzed using MATLAB software. The signal gain of the whole circuit is as high as 80dB, and the circuit has strong anti-interference ability and high temperature resist. The amplification to the signal above 1μV is good, which is satisfied with the parameter test system of drilling engineering.**

Keywords-Microvolt signal; Signal amplifier circuit; Resistance strain sensor; AD8552; Drilling engineering

I. INTRODUCTION

In the petroleum exploration and development, the well drilling project is the complex system engineering. Measuring the drilling engineering parameters is highly significant to improve drilling efficiency and fundamental research of the well drilling theory. Whether it is directional and horizontal wells or vertical wells, in order to better control the drilling process, drilling engineers need to accurately understand and master the underground engineering parameters [1].The development direction of modern technology is directly to get the drilling pressure, torque and other engineering parameters in the underground near drill bit. Compared to the ground profile logging, its accuracy is higher, and could more truly reflect the underground situation. The engineering parameters are needed to use in the rotary steering drilling system, geological steerable drilling system and the NDS drilling system [2][3]. Therefore, the measurement of the drilling pressure, torque and other engineering parameters is very important to the drilling project. To measure the drilling parameters near drill bit, these parameters need to be changed by a non-power into electricity through the sensor. In the amplification process of sensor output signal, the larger output signal is likely to be amplified, but the microvolt signal amplification is far more complex and more difficult. The microvolt signal is very weak, however other signals, such as the floor noise of the sensor, inherent noise of amplifier circuit and underground interference noise, are often much larger than the useful signal amplitude. So the weak signal can not be detected only relying on amplification. In order to extract useful signal, it need to suppress effectively noise and amplify weak signals. For the low-frequency microvolt signal, the paper designed a high signal-to-noise ratio microvolt signal amplifier circuit. The circuit can be applied to the small signal amplification of drilling engineering parameters and other small signal amplification.

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II. THE TEST SYSTEM OF DRILLING ENGINEERING PARAMETERS

Using a variety of sensors, the testing system of drilling engineering parameters could realize the real-time acquisition of the underground engineering parameters. It mainly collects the drilling pressure, torque, lateral force and annulus pressure. The acquisition signal is adjusted, amplified, and transmitted to the control center through the cable. Through the comprehensive analysis of the drilling engineering parameters, it could understand the current drilling status in detail, and timely adjust the drilling engineering parameters, thereby ensure the drilling job completing successfully [4]. System block diagram is shown in Figure 1.

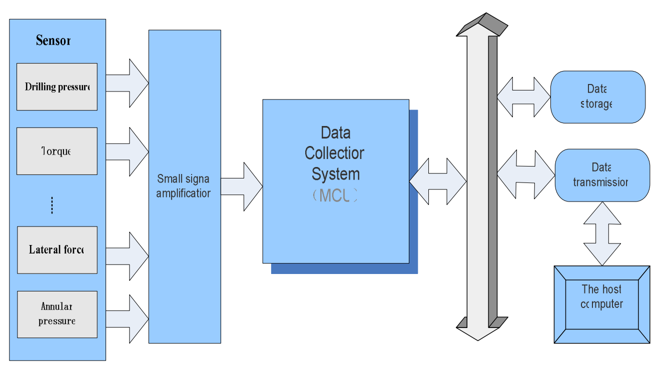

Figure 1． System block diagram

At present, the data acquisition, data storage and data transmission of the testing system are relatively mature, but the downhole sensor and the amplification of the sensor output signal are in the stage of research and development. For the drilling engineering parameters, the voltage of the sensor output signal is low-frequency signal from zero to tens of microvolt. The low frequency signal in the millivolt amplifier technology has been quite mature, but the low frequency signal in the microvolt amplifier technology is under development. It would achieve the microvolt signal amplification in the bad underground environment of high temperature, high pressure, strong vibration and strong interference, and circuit energy consumption and circuit occupied space as small as possible, which put forward the higher request to the performance and design of amplifier circuit.

III. SIGNAL AMPLIFIER CIRCUIT DESIGN

A. The system framework

The system mainly consists of the sensor circuit, amplification circuit and power circuit. Among them, the sensor circuit realizes the non-power into electricity; the circuit consists of two amplifier circuits. One is the zero-drift, rail-rail op amp AD8552, which achieves the first stage amplifier. The second stage amplifier is achieved by TLV2252. Power circuit provides a stable and reliable voltage for the sensor circuit and amplifier circuit. The design uses a voltage regulator chip WDY05S03.

B. The sensor circuit

The system joins a measuring spindle as the elastomer in the drill string, and completes the group bridge strain gauge pieces of cloth on the measuring spindle. The internal of resistance strain sensor is composed of four strain gauge bridge circuit, and constitutes the arm bridge circuit. The stress strain is deformation when forced, and the corresponding resistance value changes, so that the bridge is out of balance. In the case of external power supplying for bridge, it uses the bridge difference to detect the measured signal. The constant voltage source is used for the circuit's power supply [5]. The structure of the sensor circuit diagram is shown in Figure 2. When the sensor is not affected by the force, in theory,

$$R1 = R2 = R3 = R4 = R \quad (1)$$

the circuit output is zero. However, the output is often not zero because of bridge unbalance composed by the precision resistor. It needs to compensate the bridge to make the output zero.

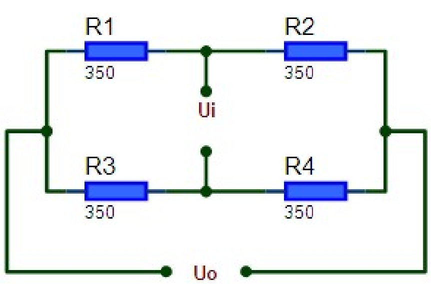

Figure 2. Sensor structure diagram

When a force acts on the sensor, the arm resistance value of each bridge will change. By reasoning, the change value between output and resistance has the following relation:

$$U_0 = \frac{4\Delta R U_i}{R}. \quad (2)$$

From the formula above, when constant pressure source for power supply, the sensor output signal voltage U_0 is proportional to the dependent variable of resistance strain gauge. The sensor output is related to power supply voltage and precision. The drilling engineering parameter tester, which measures sensor output is 0 ~ 130μv using by multimeter, requires a minimum resolution of the circuit for 1μV. Such a tiny signal is highly interfered by noise. In order to effectively collect the useful signal, it is the key to enlarge the useful signal and effectively suppress or eliminate the interference signal.

C. Signal amplifier circuit design

According to the characteristics of the strain sensor output signal, the amplifier design is high power gain and low noise. On one hand, the most direct measure to increase the gain is the cascade of multiple amplifiers. This structure increase the gain, meanwhile introduce the noise interference. The more the series, the more the circuit transfer function poles, which results in system instability. So it commonly uses two-stage cascade[6]. On the other hand, multi-stage amplifier noise depends primarily on the first stage amplifier circuit. It is extremely important to select the op amp of first stage amplifier circuit.

For the microvolt signal, the ordinary op amps could not be used. The input offset voltage of ordinary op-amp is generally in the hundreds of microvolt or more, but the offset voltage temperature coefficient is above zero microvolt [7]. Although the input offset voltage could be zeroed, it is difficult to eliminate its drift. AD8552 produced by AD Company has superior performance of low noise, zero drift, single power supply and high input impedance, which provides a good choice for the low-frequency microvolt signal detection.

Microvolt signal amplification circuit use two stage amplification: the first stage amplifier using zero-drift, rail-to-Rail Operational Amplifier AD8552; the second stage using the TLV2252 as a signal regulator and filter. AD8552 is used for the first stage amplifier; TLV2252 is used for the second stage as a signal regulator and filter. The whole circuit is shown in Figure 3, the front end is the sensor circuit; the middle part is the first stage amplifier circuit; the last part is the second stage amplifier circuit.

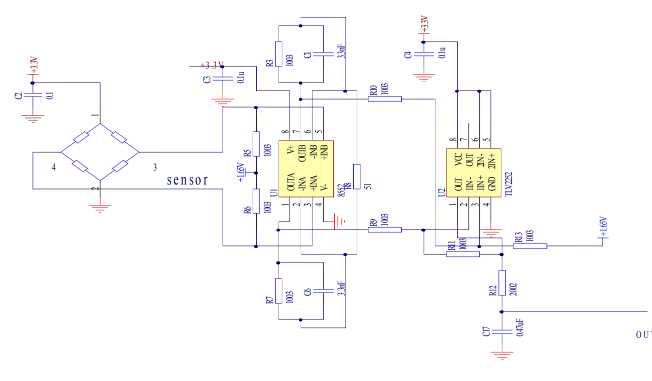

Figure3. Microvolt signal amplifier circuit

AD8552 is the core of the first stage amplifier circuit. In order to improve the amplifying circuit precision and common mode rejection ratio, R3, R5, R6, R7 and R8 use the high-precision resistance,

$$R3 = R5 = R6 = R7 = 100K\Omega \tag{3}$$

$$R8 = 20\ \Omega \tag{4}$$

In theory, the circuit magnification could be calculated for 10001 times. C1 and C6 are used to filter out high frequency noise in the signal, and C3 is used as a power regulator and filter. To make output signal stable and reliable, TLV2252 is used to stabilize the output of the first stage amplifier; C4 is used as power regulator and filter. R12 is used for anti-system jitter [8]. C17 is used to filter the AC component of the output signal, which making output signal more stable.

In order to realize the test data of positive and negative direction, the output signal zero is set to 1.65V. It could adjust the circuit zero in use. The resistance R8 could also be changed according to actual need, so that could change the gain of the amplifier circuit.

IV. EXPERIMENTAL RESULT AND ANALYSIS

According to the circuit design, the hardware circuit is produced. Through experiment, the following table Ⅰ shows experimental data of the amplifier circuit input and output. U_i is output microvolt signal of resistance strain sensor circuit under strain. U_0 is output voltage of amplifier circuit.

TABLE I. AMPLIFIER INPUT AND OUTPUT EXPERIMENTAL DATA

input U_i（μV）	output U_0（V）
1.0	1.51
3.0	1.49
6.0	1.46
15.0	1.36
33.0	1.21
43.0	1.13
58.0	0.96
67.0	0.84
75.0	0.75
81.0	0.69
98	0.5
113	0.35
128	0.21

According to the data in table 1, use the MATLAB for the least square method curve fitting, and carry out the curve fitting of first order, second order, third order and fourth order. The fitting curve is shown in Figure 4. It could directly observe the first order fitting effect best from figure4, which is consistent with the design principles. Through the above method, it could get the fitting line:

$$U_0 = 0.0103\ U_i + 1.5324. \tag{5}$$

It could be seen that the amplifier magnification is about 10,300 times, and the result is basically equal compared to the pre-designed 10001 times. The result analysis shows that the microvolt signal amplifier circuit could meet the need of the amplification range and has the good amplification linearity.

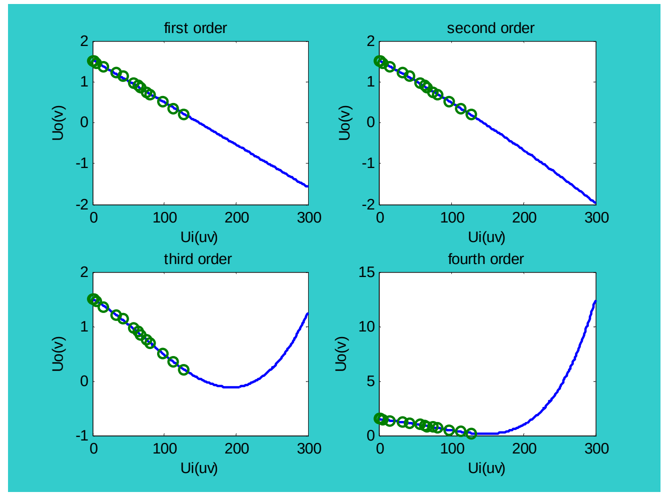

Figure 4． Curve fitting of first, second, third, fourth order

V. CONCLUSIONS

The small signal amplifier circuit of drilling engineering parameter test could realize the microvolt signal amplifier, which magnification could reach 10000 times. The circuit could resist 125 ℃ high temperature and be in the bad underground environment. During the drilling process, it could also amplify the small signals such as the drilling pressure, torque, lateral force and annulus pressure etc, especially for microvolt signal of the sensor output. Several experiments show that the microvolt signal amplifier circuit is stable and reliable, strong anti-interference ability and good practicability, so it could be well applied to the testing instrument of drilling engineering parameter.

In the process of the circuit hardware production, besides theoretical analysis and noise coefficient[9], it also need to pay attention to the following questions: (1) because the output ripple of switching power supply is too large, it could not be used for the amplifier power supply, so use a linear power supply or battery for power supply; (2) had better shield the amplifier circuit; (3) the negative feedback resistance must have sufficient accuracy and high temperature resistant, and closed-loop gain of the circuit could not be too large.

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