Strain Micro Signal Amplification Circuit Design for Nanopositioning Stage

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Abstract

Strain gauge is an important sensor. It is a resistance sensor that can be used to measure changes in physical quantities such as force and pressure. It can accurately detect small deformations or displacements of components. In order to improve the detection rate and measurement accuracy of strain gauge signals, it is crucial to design high-performance signal amplification and processing circuits. This paper designs a new amplification circuit for the weak signals of strain gauges. This circuit first uses the OP07 operational amplifier to construct a differential amplifier, which can effectively suppress common mode noise and amplify the weak bridge circuit output signal. Using a filter circuit to filter the amplified signal can effectively suppress high-frequency noise. Experimental results show that the designed amplifier circuit can achieve accurate detection of small signals. The circuit design idea is simple and reliable, and is of great significance for improving the detection accuracy of strain gauge signals.

Keywords

Strain Gauges; Feedback; Sensor; Amplifying Circuit.

1. Introduction

Signal amplification circuits are widely used. In signal processing circuits, it is usually necessary to amplify small signals to facilitate subsequent signal processing. Zhen Guoyong and others designed an amplification measurement circuit with the instrumentation amplifier AD636 as the main component, and used a high-precision optical separator to isolate the impact of the collection end on the signal [1]. Based on Multisim simulation, He Xiaoyong analyzed high-frequency power amplifiers and high-frequency small signals, and compared the similarities and differences between the two amplifiers [2]. Si Kaibo et al. artificially effectively solved the interference and offset errors in the signal amplification circuit, and proposed to use precision instrumentation amplifiers and self-zeroing technology to amplify weak signals. The precision instrumentation amplifiers achieve higher common mode rejection ratios, and the self-zeroing technology reduces offsets. Error, the combination of the two can achieve stable and effective amplification of weak signals by 110 times [3]. In the high-speed fragmentation parameter testing system, Li Zhicheng and others used photoelectric detectors as signal conversion devices to test fragmentation speed, size and other parameters, and analyzed the high-frequency small signals generated by the sensors. The operational amplifier implements the preamplification function, and the OP27 operational amplifier implements the main amplification function. The high-pass filter circuit and the main amplifier circuit together constitute a voltage-controlled voltage source second-order high-pass filter circuit [4]. Xu Xingming

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and others designed a small signal amplification circuit. The amplification circuit uses the high-precision instrumentation amplifier AD623 as the core device. Different gains can be selected according to the size of the input voltage signal, achieving accurate voltage signals in the range of 1mV to 1V. Amplification, at the same time, the amplifier also has the advantages of suppressing common mode interference, suppressing temperature drift, good stability, and strong anti-interference ability [5]. In drilling engineering experiments, Hu Ze and others used strain sensors as signal conversion devices and used the high-precision rail alignment operational amplifier AD8552 as the core device to test parameters such as drilling pressure, torque and lateral force. The overall amplification gain was as high as 80db. , the circuit has strong anti-interference ability and high temperature resistance, and has good amplification effect on signals above 1uv [6]. When Yang Xinlei and others were testing the two-dimensional high-frequency rotating magnetic properties of ultra-microcrystalline alloy samples, they designed a design to address the problem that the sensing signal in the B-H composite hysteresis vector sensor is weak and susceptible to interference from the surrounding electromagnetic environment and produces a lot of noise. A high-frequency small signal amplification circuit composed of a differential amplifier with high-performance instrumentation amplifier AD8221 as the main component, a high-pass filter, a low-pass filter, and a DC bias adjustment circuit. This hardware circuit was applied in the calibration experiment of the H coil, and the calibration coefficient of the H coil was determined [7].

2. Strain Measurement Amplifier Circuit Design

2.1 Strain Principle and Strain Gauge Selection

The composition of the strain gauge usually consists of a sensitive grid, a base and a covering layer. The base is used to fix the sensitive grid and prevent the shape, position and size of the sensitive grid from changing. The covering layer can effectively isolate the influence of external dust and humidity to protect the sensitive gate. As shown in Figure 1.

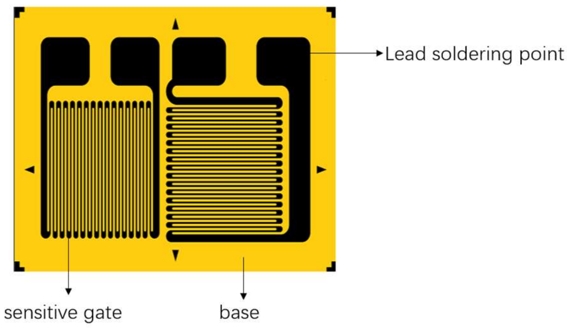

Figure 1. Strain structure diagram

The working principle of the resistance strain gauge is based on the strain effect of the material. The strain gauge is attached to the surface of the measured object. When the measured object is mechanically deformed by external pressure, the length of the resistance wire coiled inside the strain gauge also changes accordingly. The root resistivity is ρ, the length is L, and the cross-sectional area is S. The resistance value without external force is:

$$R=\frac{\rho * L}{S} \quad (1)$$

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When the resistance wire is acted upon by an external force F, the original length L will change by ΔL, and the area will change accordingly by ΔS. As a result, the resistivity will also change, and this variable is Δρ. The relative change amount of the corresponding internal resistance value is:

$$\frac{\Delta R}{R}=\frac{\Delta L}{L}-\frac{\Delta S}{S}+\frac{\Delta \rho}{\rho} \tag{2}$$

Among them, the strain ε can be expressed by the change in length:ε=ΔL/L

ΔS/S is the change in the cross-sectional area of the resistance wire:

$$\frac{\Delta S}{S}=\frac{2\Delta R}{R} \tag{3}$$

Based on the knowledge of material mechanics, when the metal wire is subjected to an external force F, it will elongate in the axial direction and shorten in the radial direction. Then the relationship between the two can be replaced by:

$$\frac{\Delta R}{R}=-\mu\frac{\Delta L}{L}=-\mu\,\varepsilon \tag{4}$$

where μ is the Poisson's ratio of the material, and the negative sign represents the opposite direction. Common Wheatstone bridges for strain gauges include single bridge, double bridge, and full bridge. However, the measurement accuracy of a single bridge is low, about 0.1%. Measurement results may be affected by connecting lines. Usually used to measure low resistance. The double bridge is limited by the potential difference measuring device, and the measurement accuracy depends on the sensitivity of the potential difference measuring device. And the requirements for wiring and contact are relatively high, otherwise the error will be relatively large. This paper will choose a strain gauge composed of a full-bridge circuit, as shown in Figure 2. Its advantages are high precision, which can eliminate errors caused by environmental changes and temperature changes; high sensitivity, and is widely used in fields such as material mechanics testing and structural deformation testing. . The internal structure consists of four strain gauges arranged in the form of a Wheatstone bridge. When strain gauges No. 1 and 3 are under compressive stress, strain gauges No. 2 and 4 are under tensile stress. When the stress causes the resistance of the four pieces to change, the unbalanced voltage of the bridge can be detected. From the bridge unbalanced voltage, the strain and stress can be calculated.

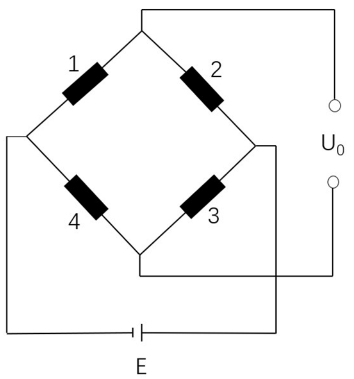

Figure 2. Full-bridge circuit structure

2.2 Amplification Circuit Design

Since the voltage value output by the strain gauge is very weak, in order to facilitate the measurement of the actual voltage value, the weak voltage signal needs to be amplified. This article requires a detection system that can measure micro-nano level displacement, and uses op07 two-stage precision amplification components to ensure voltage amplification at the same time. Ensure sufficient accuracy. From the circuit connection diagram in Figure 3, we can see that the input signal is introduced from the reverse input end, and the picture shows the reverse amplifier. According to the virtual short and virtual break of the circuit, we can know the relationship between the input voltage and the output voltage.

$$u_o = -\frac{R_f}{R1} u_i \tag{5}$$

The closed-loop voltage amplification factor is:

$$A = \frac{u_o}{u_i} = -\frac{R_f}{R1} \tag{6}$$

The negative sign indicates that the phase difference between the output signal and the input signal is 180°.

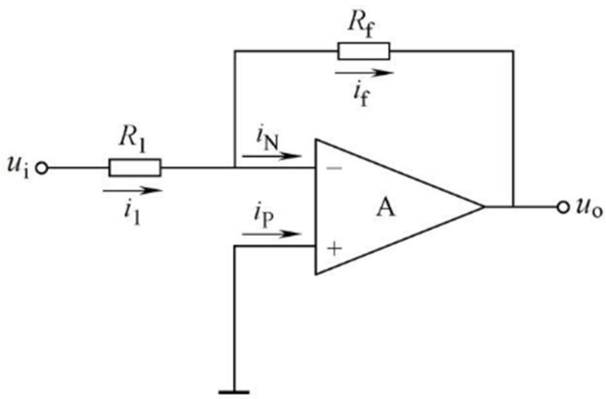

Figure 3. Inverse amplifier

As shown in Figure 4, in the two-stage amplification circuit, the op07 amplification chip is used. This chip integrates low noise, high precision, wide bandwidth, low offset, high output and other characteristics. It is an operational amplifier with excellent performance and is suitable for various applications. Precision instrumentation, sensor signal processing and other occasions. Adjust the amplification factor by adjusting the size of the feedback resistor. Design an RC filter circuit at the input end of the circuit to filter out RF high-frequency interference signals at the output end. It should be noted that RC devices with the same specifications must be selected, otherwise differential mode interference will be caused. The low-pass filter is mainly used to filter high-frequency components in the circuit, and can effectively reduce interference when AD is working. Remove invalid signal input. Common low-pass filters include Butterworth filter, Bessel filter, Chebyshev filter, and Elliptic filter. This article uses the Butterworth filter because it is the flattest in the passband area and has the smallest attenuation in the corresponding frequency range. Reduce the impact of noise.

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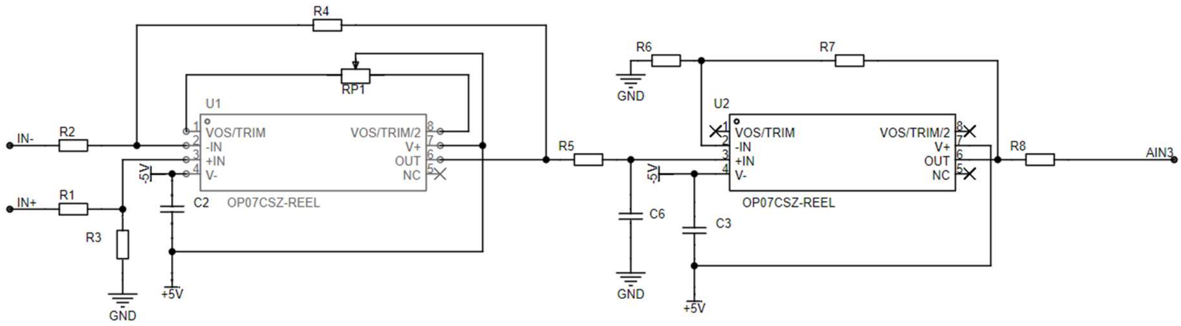

Figure 4. Two-stage precision amplifier circuit

3. Physical Production and Experiment

Use professional drawing software to draw the schematic diagram of the designed circuit diagram, as well as PCB layout and adjustment, and finally make a physical diagram. As can be seen from Figure 5, the left terminal is connected to the four pins of the full-bridge strain, which are the voltage positive and negative pins. , the input signal is positive, the voltage is negative, the input signal is negative, the right terminal can be connected to any microcontroller interface, which are the signal output terminal, voltage positive terminal and ground terminal respectively.

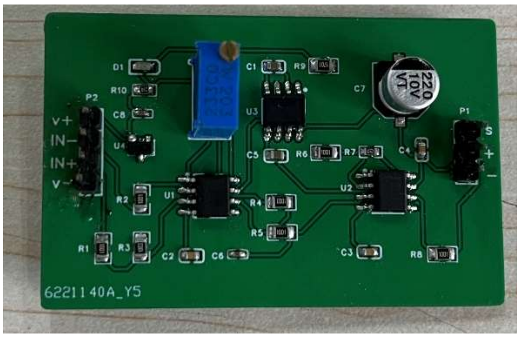

Figure 5. Physical diagram of amplification circuit

Paste the strain gauge on the surface of the mechanical structure, and then connect it to the microcontroller through the amplification circuit module. The Dspace device applies voltage to the piezoelectric ceramics. By controlling the corresponding displacement of the voltage output of the piezoelectric ceramics, the amplified strain value and The relationship between the structural output displacement and the data can be concluded that when the same spacing voltage is applied, the strain amplification voltage and the displacement output show a good linear relationship. As shown in Table 1.

Table 1. Experimental data

Piezoelectric ceramic voltage(v)	Strain amplification voltage(mv)	Displacement output(μm)
0	10	0
3.75	18	0.3
7.5	26	0.65
11.25	38	1.05
15	46	1.47
18.75	59	1.9
22.5	68	2.4

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4. Conclusion

This paper designs a new amplification circuit for weak signals from strain gauges. This circuit uses an OP07 operational amplifier to construct a differential amplifier to suppress common mode noise, and then uses a filter circuit to suppress high-frequency noise. Experimental results prove that the designed amplification circuit can detect small signals and amplify them, achieving accurate detection of micro- and nanoscale displacements. The differential amplifier is used to effectively suppress common mode noise and improve the signal-to-noise ratio; the filter circuit suppresses high-frequency noise and improves the output signal quality. The amplification circuit design is simple and reliable, and easy for practical application.

This research provides a high-performance amplification solution for strain gauge signal detection, which can significantly improve the practicality of strain gauges in micro deformation and displacement measurements. This circuit design idea can be applied to the precise detection of more tiny physical quantities.

Acknowledgments

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