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Abstract: In this paper we put forward the basic structure of a micro-displacement measuring system based on the basic theory of laser feedback, and designed a hardware circuit of the system, including the LD driver and modulation circuit, photoelectric signal amplifier and filter circuit, which meet the requirements of the follow-up experimental study by theoretical analysis and Multisim simulation to the circuit.

Keywords: Laser feedback, Micro-displacement measurement, Hardware circuit design.

1. Introduction

With the rapid development of laser technology, measurement technology and computer digital processing technology, the accuracy of micro-displacement measurement is increasing. The micro-displacement measurement based on the laser self-mixing interference technology becomes a new research hotspot at home and abroad, because the study of laser self-mixing interference theory based on the optical feedback effects is more fruitful. As the laser measurement is non-contact, high precision and good robustness, this technology is widely applied to various fields, including scientific research and modern industrial production.

Laser self-mixing interference achieved in the laser cavity. When LD output light is reflected or scattered by an external object, part of the light is fed back to the laser resonator and mixed in the cavity. Feedback light carries the information of the external object movement. When the relative displacement of the external reflector changes, the amplitude and phase of output optical power change accordingly. So we can obtain the displacement of the moving object by detecting the output optical power.

In this paper we design the hardware circuit of the micro-displacement measurement system, including the LD driver and modulation circuit, photoelectric signal amplifier and filter circuit, and prove the effect of the circuit through theoretical analysis and Multisim simulation.

2. The Basic Structure of the System

The basic structure of micro-displacement measurement system of laser self-mixing interference is shown in Fig. 1. The system measures the micro-displacement of external reflector driven by PZT, outputting the reconstructed displacement signal by detecting and processing laser interferometer signal [1-3]. The adjustable attenuator in system can
adjust the laser feedback level. Laser diode (LD) output light irradiate to the external reflector after collimated by micro lens. The feedback light and the light inside happen self-mixing interference. Photodetector [4] (PD) can detect the output signal, and the weak signal need be transformed, amplified and filtered, in order to supply computer the accurate signal.

![Diagram of the system](image1)

**Fig. 1.** Basic structure of the system.

### 3. The Design and Theoretical Analysis of the Hardware Circuit

Depending on the system characteristics, the paper design the hardware circuit of micro-displacement measurement system of laser self-mixing interference to meet the needs of the experiment, including the LD driver and modulation circuit, the optical signal amplifier and filter circuit, and makes the theoretical analysis.

#### 3.1. The Monitoring Principle

The output optical power of LD can be modulated by the injection current [5], because when the injection current is greater than the threshold current ($I_{th}$) within a certain range, the output optical power and injected current is approximately proportional relationship. Using this feature, the output optical power can be modulated fast and perfectly. The current modulation characteristic is shown in Fig. 2.

![Current modulation characteristic](image2)

**Fig. 2.** The current modulation characteristics of LD.
Fig. 3 is the LD driver and modulation circuit, including voltage signal inputting circuit, in-phase proportion amplifying circuit, relay protection circuit and the LD driver circuit. Vb is precision reference voltage, driving the LD to work normally; Vm is modulation voltage, offered by signal generators, outputting sine, triangle and square wave signal to modulate the LD.

![LD driver and modulation circuit](image)

The operational amplifier A1 and A2 output in the form of a voltage follower, eliminating the influence of the load change on the output voltage, to achieve impedance isolation. The input voltage \(V_{in}\) is superposition of the reference voltage Vb and modulation voltage Vm. In the case of \(R_1 = R_2\), the expression of \(V_{in}\) is as follow.

\[
V_{in} = R_1V_b'/(R_1 + R_s) + R_2V_m'/(R_1 + R_s) = 1/2(V_b' + V_m')
\]  
(1)

The operational amplifier A3 is noninverting proportional amplifier, amplifying the input signal \(V_{in}\).

\[
V_{out} = (1 + R_a / R_s)V_{in}
\]  
(2)

LD driver circuit is composed of op-amp A5 and Darlington transistor compound of Q1 and Q2. Characteristics of the op-amp have seen \(V_c \approx 1/2 V_{cc}\), and suppose \(R_s = R_g = R_4 = R_{10}\), so it can be seen,

\[
V_{out} - V_{cc}/2 + \left(V_{in} - V_{R_1}\right) - V_{out}/2 = 0
\]  
(3)

So \(V_{R_1} = V_{out}\), and

\[
I_{LD} = V_{out}/R_{10} = \frac{1}{2} \left(1 + \frac{R_s}{R_{10}}\right)(V_b' + V_m')
\]  
(4)

We can see \(V_{out}\) is unaffected by power \(V_{cc}\) fluctuation, proportional with \(I_{LD}\). Relay protection circuit prevents the laser current is too large effectively, composed of the comparator A4 and the relay J. The reference voltage \(V_{ref}\) can be changed by adjusting \(R_4\). When \(V_{out} > V_{ref}\), the comparator A4 outputs high level, to make normally closed switch K of the relay J disconnect. So LD does work, for the base of Darlington transistor cutoff due to no input current; When \(V_{out} < V_{ref}\), the LD work normally [6].

3.2. The Optical Signal Amplifier and Filter Circuit

Fig. 4 is optical signal detection and amplifier circuit. The interference signal detected by PD is quite weak, so this paper describes one kind of instrument amplifier circuit to amplify the weak signal, with the characteristics of high stability gain, strong ability to suppress common mode interference and low temperature drift. PD using silicon photodiode, convert optical signal into electrical signal, and incorporate a precision resistor R to achieve current and voltage conversion. Instrument amplifier circuit arranges into two grades adopting three operational amplifiers: one is a preamplifier composed of two operational amplifiers, and the other is a differential amplifier. The preamplifier provides high input impedance, low noise and high
gain; The differential amplifier suppresses common mode noise.

\[ \text{Vout} = \frac{V_2}{V_1} \left( 1 + \frac{2R_3}{R_2} \right) \left( V_{i1} - V_{i2} \right) \]  

Voltage gain is

\[ A = \frac{V_{out}}{V_{i1} - V_{i2}} = \frac{V_2}{R_1} \left( 1 + \frac{2R_3}{R_2} \right) \]  

It can be seen, voltage gain is related to R2/R1 and R5/Rg. Select different resistance to achieve different signal amplification ratio. But considering the stability and safety of the circuit, only Rg can be adjustable, R1–R6 are fixed.

Fig. 5 is signal filter circuit. As the signal detected and amplified has some high-frequency noise, needing further processing. The paper designs a second-order active low-pass filter, filtering out high frequency noise, to get high-quality signal. In order to facilitate the design, suppose R1=R2=R, C1=C2=C, so passband cutoff frequency \( f_c = \frac{1}{2\pi RC} \),

passband magnification \( A_0 = 1 + \frac{R_f}{R_3} \).

4. Multisim Simulation and Analysis

Fig. 6 is the simulation of the LD driver and modulation circuit, parameter setting shown in figure. The reference voltage supplied by V1, being sine wave signal whose amplitude is 2 V and frequency is 50 Hz; The modulation voltage is supplied by signal generators, outputting sine, triangle and square wave signal to modulate the LD. Modulation waves are shown in Fig. 7 and Fig. 8. As shown, Drive signal LD can effectively work, and LD output power modulation. The signal can drive the LD work effectively, and modulate the output optical power of it [7-9].

\[ V_{out} = \frac{R_2}{R_1} \left( 1 + \frac{2R_3}{R_2} \right) (V_{i1} - V_{i2}) \]
Fig. 5. The second-order active low-pass filter.

Fig. 6. The simulation of the LD driver and modulation circuit.

Fig. 7. Square wave modulation signal.

Fig. 8. Triangular wave modulation signal.
Fig. 9 is the simulation of the amplifier circuit, parameter setting shown in figure. The signal magnification $A_v = -\frac{R_v}{R_4}(1 + \frac{2R_4}{R_v}) = -201$. As the Fig. 10 input and output waveforms shown, the results fit with the theoretical analysis, so it meets the requirement of the circuit design.

![Fig. 9. The simulation of the amplifier circuit.](image1)

![Fig. 10. The input and output waveforms.](image2)

Fig. 11 is the simulation of the filter circuit, parameter setting shown in figure. Passband cutoff frequency $f_0 = \frac{1}{2\pi R_5 C_1} = 100kHz$, and passband magnification $A_0 = 1 + \frac{R_4}{R_3} = 2$; The amplitude-frequency characteristic is shown in Fig. 12, 3 dB cutoff frequency is about 126 kHz. Fig. 13 and Fig. 14 are low-frequency and high-frequency signal input and output waveforms respectively. As shown in figure, the low frequency signals below 100 kHz can pass effective, so it can suppress high frequency signals effectively.

![Fig. 11. The simulation of the filter circuit.](image3)

![Fig. 12. The amplitude - frequency characteristic.](image4)
noise to get high-quality signal. It can meet the requirements of the follow-up experimental study by theoretical analysis and Multisim simulation to the circuit.

References


6. Conclusions

This paper based on the basic theory of the laser self-mixing interference, puts forward the basic structure of the self-mixing interference micro-displacement measurement system, and designs the LD driver and modulation circuit, the optical signal amplifier and filter circuit. The LD driver and modulation circuit produces stable working current, modulating the current signal cooperating with the signal generator [10]. Furthermore, the paper designs the relay protection circuit to protect the LD. The optical signal amplifier circuit achieves the amplification of the weak signal. The second-order active low-pass filter circuit filters out high frequency