Design of the Circuit for IPMC Micro-force Sensor and Testing

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Abstract: The IPMC has perceived performance, so it can be used for making micro-force sensor. But its sensing signal is very weak, a greater influence on perception from the environmental noise signals. In the paper, we design a micro-force sensor system based on IPMC. The current signal conversion of analog circuit, voltage signal amplification, signal processing and other key parts are introduced, meanwhile, the calibration to micro-force sensor is completed. Copyright © 2014 IFSA Publishing, S. L.

Keywords: IPMC, Micro-force sensor, Charge amplifier, Conditioning circuit, Calibration.

1. Introduction

With the development of Nano biotechnology, measuring micro-force under small environment is paid attention to by people. The traditional measurement equipment cannot meet the need of small environment. For this reason, people made various types of MEMS micro-force sensor using all kinds of materials with physical mechanism [1].

IPMC (Ion-exchange polymer metal composite) is a kind of novel artificial intelligent materials. Through the electroless plating process, the gold, platinum and other precious Metal are plated on the two surface of ion exchange membrane to form a "sandwich" structure [2]. As a new material, the obvious advantages are, such as lightweight, good flexibility, easily cut in any size and shape without being affected the actuator and sensing characteristics. It will generate a large displacement when applied a low drive voltage, on the other hand, it also will generate weak perceived charge when IPMC has bending deflection under mechanical stimulation [3, 4]. Based its sensing characteristic, in the paper, we study a micro-force sensor used to measure the force that the probe applying on the cell during the cell injection.

In the IPMC micro-force sensor system, because IPMC's perception signal is very weak, and is affected seriously by the noise signals from the environment, in order to obtain the useful perception
signal, we need make the signal being converted, amplified processing, so designing analog circuit is one of the most important step in the IPMC micro-force sensor system.

2. Design of the Analog Circuit in the Micro-force Sensor System

2.1. Design of the Charge Amplifier

The core of charge amplifier circuit is to convert the perception charge produced by the force on IPMC into a voltage signal. Its circuit structure is as shown in Fig. 1. The box part of the figure is a charge source connected with a capacitor in series, which is equivalent to the sensor. From the functional perspective, it is a charge generator, also a capacitor. The charge amplifier is a kind of deep capacitor negative feedback amplifier, whose output voltage signal is proportional to input charge signal, with high input impedance [5].

Fig. 1. The schematic diagram of charge amplifier.

To add a feedback resistance in the electric charge amplifier circuit plays an important role to integral capacitor, which builds a negative feedback channel, that is, it provides DC negative feedback for integral capacitor, in order to improve the stability of the circuit. The charge amplifier circuit diagram is as shown in Fig. 2.

Fig. 2. Circuit connection diagram of charge amplifier.

2.2. Design of the Voltage Amplifier

The amplifier used in the voltage amplification circuit usually can be divided into two categories, that is, instrumentation amplifier and operational amplifier. Due to the instrumentation amplifier with low drift, low power consumption, and high CMRR etc, so it is generally used in weak signal amplifier under noise environment. Its working principle is to put the difference small signal superposing in larger common-mode signal, able to eliminate the influence of common mode signal, at the same time difference small signal can be amplified. In the paper the voltage amplification circuit is as shown in Fig. 3.

Fig. 3. The circuit connection diagram of voltage amplifier.

2.3. Design of the Low-Pass Filter Circuit

The IPMC sensor module studied in this paper, whose output signal frequency range is not more than 55 Hz. In order to filter the noise interference, we design a low pass analog filter circuit to minimize high frequency noise interference from the system. We choose a second order a passive RC low-pass filter circuit. The passive second order RC low-pass filter network is composed of series parallel R and C, simple structure, good filtering effect [6], the circuit is as shown in Fig. 4.

Fig. 4. Circuit diagram of LPF.

2.4. The Signal Conditioning Circuit

The Signal conditioning circuit designed in the sensor system is as shown in Fig. 5. The output is 0–3 V voltage signal through the conditioning circuit, within the allowed voltage range of the ADC conversion module [7].
3. Performance Test of the IPMC Micro-force Sensor

3.1. The Platform of Performance Test

The force sensor using for calibration is fixed on the micro operation instrument. We fine-tune micro operation instrument to make it parallel moving, each parallel moving displacement is 0.1 mm.

A small force is applied on the IPMC cantilever strip through the force sensor, meanwhile, perception charge will generate on the two electrodes of the IPMC. The weak charge signal passing the front conditioning circuit and the logarithmic transform circuit arrives at the A/D conversion module of TMS320F2812.

After filtering noise by wavelet transform, the transformed analog voltage signal will be displayed on the screen of LCD1602. At the same time, in the force sensor circuit using for calibration, signal is collected into the computer through the data acquisition card PCI – 6221. We use preserve the force signal by LabVIEW virtual instrument. By fitting the curves of the micro-force signal and the voltage signal with least squares method, we can get the sensor model.

We built the performance test platform of IPMC micro-force sensor according to the above experiment scheme, as shown in Fig. 6, and then determined the relationship of the force and the voltage from the IPMC cantilever micro-force sensor.

3.2. The Experimental Results

The actual model of IPMC micro-force sensor is following (1).

\[ F = 4.6516V - 0.6585, \]  
\[ F = 4.9407V - 0.5928, \]  

where \( F \) is the force, and its unit is mN, \( V \) is the perception voltage, and its unit is V.

The maximum error:

\[ e_{\text{max}} = \frac{|F_{\text{p max}} - F_{\text{v max}}|}{F_{\text{v max}}} \times 100\% = 7.02\% \]  

(3)
In the paper, sensitivity of the IPMC micro-force sensor is 0.2150 V/mN. Resolution is 0.065 mN. Linearity is ±7.21%. Dynamic range is 80 dB. Measurement range is (0~13 mN).

4. Conclusion

In the paper, the analog circuit of IPMC micro-force sensor is designed, including mainly the charge amplifier circuit, voltage amplifier circuit, which is respectively used to extract the weak current signal and small voltage signal. The filter circuit designed is effective to reduce the effects from the environmental noise. Using the signal conditioning circuit to build the test platform, we complete calibration to the IPMC micro-force sensor.

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