

## Research on PVDF Micro-force Sensor

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**Abstract.** At present, sub-micro-Newton (sub- $\mu$ N) micro-force in micro-assembly and micro-manipulation is not able to be measured reliably. The piezoelectric micro-force sensors offer a lot of advantages for MEMS applications such as low power dissipation, high sensitivity, and easily integrated with piezoelectric micro-actuators. In spite of many advantages above, the research efforts are relatively limited compared to piezoresistive micro-force sensors. In this paper, Sensitive component is polyvinylidene fluoride (PVDF) and the research object is micro-force sensor based on PVDF film. Moreover, the model of micro-force and sensor's output voltage is built up, signal processing circuit is designed, and a novel calibration method of micro-force sensor is designed to reliably measure force in the range of sub- $\mu$ N. The experimental results show the PVDF sensor is designed in this paper with sub- $\mu$ N resolution.

### Introduction

MEMS is Micro Electric Mechanical System. MEMS is cutting-edge technology of the 21st century based on microelectronics, micro-mechanical and materials science. It rapidly developed into an emerging field including micro mechanical, micro sensor, micro controller, signal processing and intelligent control. So MEMS attracted a large number of domestic and foreign researchers to be studied extensively.

Research of MEMS need to be supported by micro-assembly and micro-manipulation techniques. For the moment, the fast and cheap assembly of the MEMS equipment in the manufacturing process had not yet been developed, mainly because structure is brittle and easily broken in micro-measurement [1]. In micro-assembly and micro-manipulation, the typical breakthrough is force in the range of the micro-Newton. This force can not be measured reliably by most existing sensors. So the result is that components are very difficult to be assembled, the success rate of assembly is low, time is long, and the cost increases in that environment. Therefore, the automatic operation process has focused on micro-force sensing technology.

### Micro-force Sensing Methods

**Strain-gauge Sensors.** Although the strain-gauge sensors have been applied well, they also have certain drawbacks [2]. For example, strain characteristics of the material limit their measuring accuracy, and lead to large nonlinear and weak output signal. Detecting accuracy of strain-gauge sensors is generally on the milli-newton (mN) or sub-milli-newton (sub-mN) level.

**Piezoresistive Sensors.** The piezoresistive sensor and strain gauge sensor detection principle is basically the same. Detecting accuracy of piezoresistive sensors is generally on the mN or sub-mN level. For example, Zesch et al. installed piezoresistive sensor on the AFM (atomic force microscope) probe, measuring accuracy can achieve 0.1mN [3].

**Capacitive Sensors.** There are many advantages compared with piezoresistive sensors, capacitive sensors, but the difficulty of circuit design and sensor processing greatly increases with the improvement of detection accuracy. At present, the sensor resolution can reach  $\mu$ N level, but micro-force in the range of micro-Newton is still not measured reliably.

**Piezomagnetic Sensors.** In theory, the resolution of force sensors based on magnetoelastic effect can reach nano-newton (nN). As the technology is very sensitive to electromagnetic environment, the accuracy decreases to  $\mu\text{N}$  or even below sub- $\mu\text{N}$ .

**Sensors Based on Optical Technology.** Sensors based on optical technology can also be used to detect micro-force. First of all, Arai et al. developed a set of micro-force measuring device using laser Raman spectrometer method to detect micro-force [4]. Theoretical accuracy of this method is up to  $6.94\mu\text{N}$ . However, there are some disadvantages in this method, such as the slow detection speed, poor real-time. Second, some scholars use AFM to measure micro-force [5]. But the method relies on AFM, and the price of AMF is expensive and difficult to be integrated into the micro-system. Finally, optical tweezers can be used to measure micro-force. Resolution of optical tweezers can reach nN or sub-nN level. Since optical tweezers manipulate micro-objects and also measure micro-forces that are during the level of nN, which MEMS is unable to do, it does not apply to MEMS at the moment [6].

To sum up, five methods above are not reliably measured force in the range of sub- $\mu\text{N}$ . Therefore, micro-force sensor is designed based on piezoelectric materials in the paper.

### PVDF material

**PVDF.** The piezoelectric materials have been known to nearly a thousand, but piezoelectric ceramics (PZT) and PVDF are most widely applied in smart structure. First discovered in 1969 by Kawai, PVDF attracted great interest of scholars, and have carried on extensive research of preparation, properties and application in the system by the characteristics of wide frequency response, good dynamic range, high output voltage, good stability, impact resistance, etc. Superiority of PVDF in the aspects is better than other piezoelectric materials.

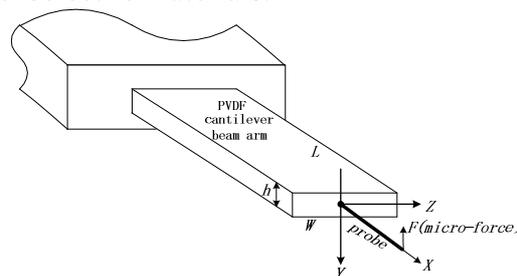


Fig. 1 Schematic diagram of a PVDF sensor's structure

### Model of micro-force

Structure diagram of PVDF micro-force sensor is shown in Figure 1. In the figure,  $W$  is PVDF width.  $L$  is PVDF length.  $h$  is PVDF Thickness.  $L_0$  is length of probe.  $d_{31}$  is piezoelectric constant of PVDF. According to the piezoelectric effect, relationship between charge  $Q$  on the surface of PVDF and  $F$  can be expressed as

$$Q = \frac{3d_{31} L(L + 2L_0)}{2h^2} F. \quad (1)$$

In practical application, it is difficult to measure the charge  $Q$ . So it is necessary to design signal processing circuit to convert charge information is to voltage information.

### Design of signal processing circuit

Since the amount of charge generated in the polarization direction is rare, the charge signals output by PVDF sensor is very weak, basically only dozens or hundreds of pico-coulomb ( $pc$ ). Therefore, the charge amplifier circuit is very important. It not only amplifies the original charge signal and makes the charge signal into voltage signal, but also matches with impedance of PVDF film to convert the high input impedance to low output impedance. Signal processing circuit of PVDF micro-force sensor schematic diagram is shown in Figure 2.

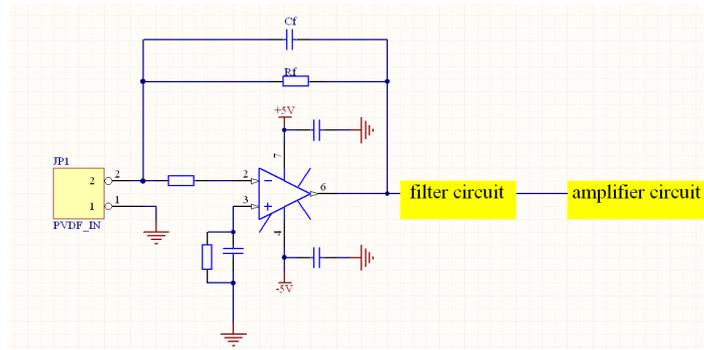


Fig. 2 Schematic diagram of signal processing circuit

Charge amplifier output  $V_{out}$  processed by filtering and amplifying can get the relationship with voltage detection signal  $V$ .

$$V = KV_{out} \frac{K}{C_f} Q. \tag{2}$$

Where,  $K$  is voltage amplification factor.  $V$  is output voltage of signal processing circuit.

The relation of PVDF sensor output voltage and micro-force can be gotten.

$$F = \frac{2h^2C_f}{3Kd_{31}L(L+L_0)} V. \tag{3}$$

### Calibration method of micro-force sensor

In the process of designing sensor, calibration is a very important step. The calibration method is divided into direct calibration and indirect calibration. Because the standard force is too small to be obtained directly, so this paper designs a novel indirect calibration method. The method is to convert the problem seeking a standard force source to seek displacement through the establishment relationship model between offset of PVDF sensor probe and micro-force.

In this paper, PVDF thin film is seen as a cantilever beam structure. This structure is shown in Figure 3.  $v$  is deflection of the cantilever beam.  $\theta$  is deformation angle.  $v_t$  is probe deflection.

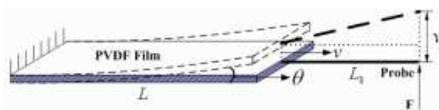


Fig. 3 Schematic diagram of PVDF cantilever beam structure

Since  $\theta$  is approximately equal to  $0^\circ$ ,  $v$  approximately equal to  $v_t$ . The relationship between the deflection of cantilever beam and force can be expressed as

$$F = \frac{6EI_z}{L^2(2L+3L_0)} v_t. \tag{4}$$

### The calibration experiment

**Parameters for PVDF sensor.**  $L$  is  $2.5 \times 10^{-2}$ m.  $W$  is  $1 \times 10^{-2}$ m.  $h$  is  $2 \times 10^{-4}$ m.  $E$  ( $E$  is the young's modulus of PDVDF.) is  $2.5 \times 10^9$ Pa.  $L_0$  is  $5 \times 10^{-3}$ m. Error of 3-D intelligent mobile platform is  $\pm 2$ nm.

**Calibration result.** To choose 20 groups force in the range of 0 to  $20 \mu$ N and calculate displacements according to the equation. Then to let platform move to each positon and record the output voltages.Finally, to repeat the above steps 5 times, calculate average voltage on each positon and draw the relation curve between force  $F$  and output voltage  $V$ .

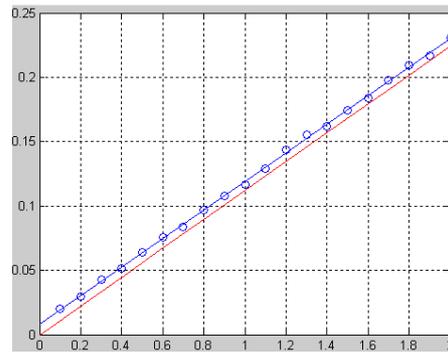


Fig. 4 Calibration curve and theoretical curve

Calibration curve and theoretical curve are shown in Figure 4. The blue line is the calibration curve and the red line is the theoretical curve. According to Figure 4, calibration curve is very close to the theoretical curve.

### Conclusion

In this paper, Sensitive component is polyvinylidene fluoride (PVDF) and the research object is micro-force sensor based on PVDF film. Moreover, the model of micro-force and sensor's output voltage is built up, signal processing circuit is designed, and a novel calibration method of micro-force sensor is designed to reliably measure force in the range of sub- $\mu\text{N}$ . The experimental results show the PVDF sensor is designed in this paper with sub- $\mu\text{N}$  resolution. At the same time, to verify the PVDF sensor model is established in this paper, and prove that the signal processing circuit and calibration method is effective. The design of the micro-force sensor is to provide reliable solutions for feedback control of micro-assembly and micro-manipulation.

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