Piezo system for X-ray beam steering

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Abstract

The project is for assembling and commissioning an optical test set-up to steer the X-ray beam at the beamline. The assembling is planned in the lab with commissioning with the laser beam. After that, it will be tested at the beamline.[1]

Contents

1 Introduction

X-ray nanoprobe technology has been widely used in recent years[2]. To get a 3D image, people either scan large samples or move the sample, however, it takes time to scan large samples, on the other hand, the movement of the sample may change environmental conditions and thus affect the sample. Therefore, it is a challenge to scan quickly.

An idea came up that to move the light rather than move the sample. Since light is massless, it is easier to move it fast. The X-ray beam will be steered by a piezo-driven mirror, where the piezo actuator is used due to the high resolution of its rotation angles and the ability to be controlled by the electrical signal.

2 Theory

The thing we should do before testing this system at the beamline is to confirm that the tilting system is operational and controllable, to achieve this, we should study the characteristics of the piezo actuator. Let us start with Piezoelectric Effect.

2.1 Piezoelectric Effect and Piezoactuator

Piezoelectric effect occurs in some specially arranged crystals. The material made by those crystals generates an electric charge when subjected to external forces. For the piezoactuator, an applied voltage to a piezoelectric material can cause it to deform. This applies the reverse reaction of the piezoelectric effect, known as the inverse piezoelectric effect.

2.2 Hysteresis

Because of the ferroelectric nature of the piezo crystals, it shows a typical hysteresis behavior[3]. When the voltage is increased, the crystal will stretch, however, when the voltage is decreased, crystals will compress with different behavioral curves, and polarization is maintained even when the electric field is removed.

2.3 Calculation of the rotation angle

Geometric diagram of the tilting mirror is shown in Figure 1,the relation between the movement of the laser and the rotation angle of the mirror follows

$$\delta p = Ltan(\theta_l + 2\theta_r) - Ltan\theta_l \tag{1}$$

where δp is the movement of the laser, L is the distance between mirror and the camera, θ_l is the angle between the mirror and incident laser, and θ_r is the rotation angle of the

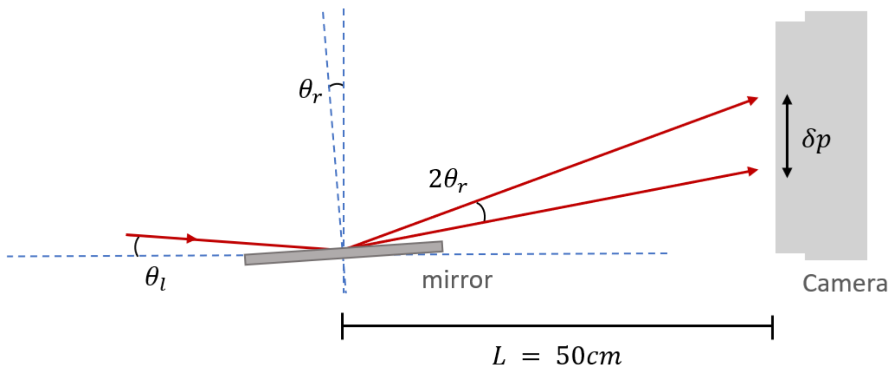

Figure 1: Geometric diagram of the tilting mirror

mirror.
Since both θ_l and θ_r are small, we can do small-angle approximations, which means

$$tan\theta \approx \theta \tag{2}$$

Eq. (1) is reduced to

$$\delta p = 2L\theta_r \tag{3}$$

and Eq. (3) can be rewritten as

$$\theta_r = \frac{\delta p}{2L} \tag{4}$$

Actually, the laser doesn't hit the rotation axis of the mirror, but the error caused by it is so small that we can ignore it here.

3 Experiment process

3.1 Experimental setup

Experimental setup is shown in Figure 2. We use piezoactuator k-201-30 [4] in our experiment. The voltage signal (0V to 10V) generated by the function generator will be amplified to a voltage suitable for the operation of the piezoactuator (-20V to 130V), we can monitor the voltage by the oscilloscope, and record the movement of the laser by Raspberry Pi High Quality Camera. Mind that because the output impedance of the function generator we are using is 50Ω, and the input impedance of the voltage amplifier and oscilloscope is high, we should connect a 50Ω resistor in parallel[5] either before amplifier or oscilloscope to achieve impedance matching.

3.2 Image processing

By sending a sinusoidal signal from the function generator, we can observe the reflected light spot moving up and down from the camera. To find the position accurately,

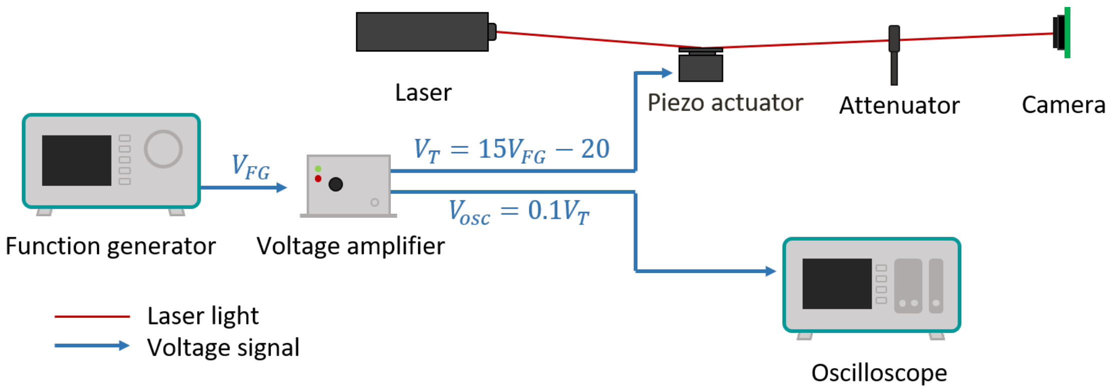

Figure 2: Experimental setup

the recorded video, as shown in Figure 3a, will go through four image processing steps.
Step1: Change the color video to an 8-bit gray scale.
Step2: To make the data look smoother, select 100 pixels height (about $0.3mm$) in the middle and take an average, now every frame of the video becomes the blue line Figure 3b, the diffraction fringes arise from diffraction at both edges of the mirror.
Step3: To find the peak position more accurately, I fitted the data with the single slit diffraction intensity distribution (orange line in Figure 3b), here we should consider the Fresnel diffraction of near-field effects.
Step4: Now collect the position for each frame, we should see a sine shape, as shown as orange dots in Figure 3c, since we input a sinusoidal signal. Finally fit this data to a sine wave (blue line in Figure 3c), where twice the amplitude of this sine wave is the movement of the laser δp.

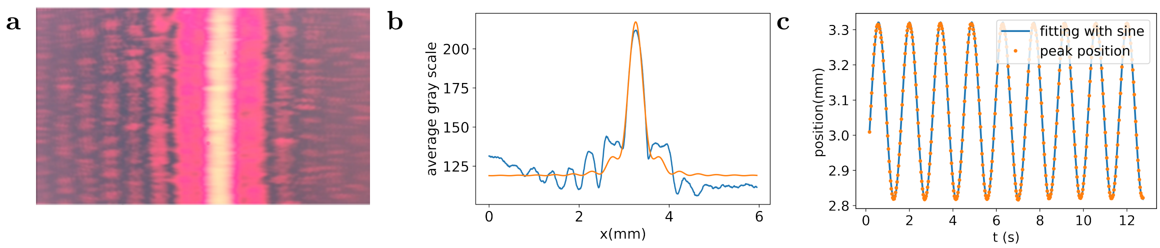

Figure 3: **a** The original video, **b** Data after averaging, where the blue line is the original data, the orange line is the diffraction distribution, **c** Peak positions in every frame, where the input signal range is 5V.

4 Measurement

4.1 Rotation angle

Recording the video by adjusting the amplitude of the input sinusoidal voltage from 0.125V to 2.5V (the highest limitation of the function generator we use), where the piezoactuator received voltage range from 3.75V to 75V, we can get the corresponding δp after image processing, then we also can find the rotation angle θ_r by Eq. 4. The relation between the rotation angle and the voltage range piezoactuator received is shown in Figure 4, X-axis and z-axis are perpendicular to each other, where the mirror lies on the xz plane. By fitting a cubic equation

$$a_3x^3 + a_2x^2 + a_1x + a_0 \tag{5}$$

we can find the rotation behavior curve in this voltage range, the parameters of the cubic equation are shown in Table 1.

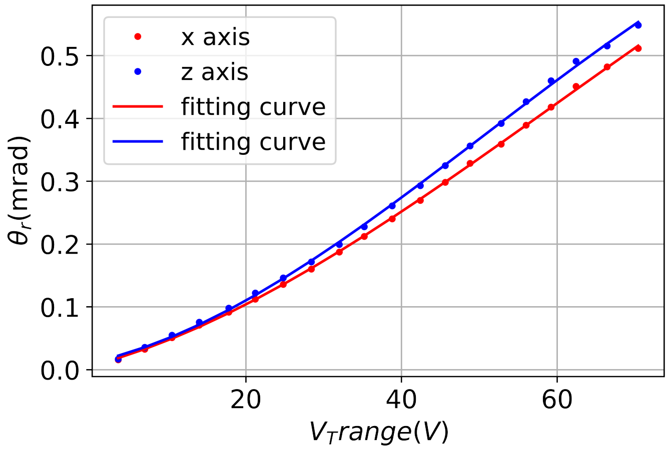

Figure 4: The relation between the rotation angle and the voltage range piezoactuator received

	a_3	a_2	a_1	a_0
x axis	-5.2×10^{-7}	9.3×10^{-5}	3.3×10^{-3}	5.7×10^{-3}
z axis	-8.8×10^{-7}	1.3×10^{-4}	2.6×10^{-3}	1.1×10^{-2}

Table 1: Fitting parameter

4.2 Hysteresis

Since the movement of the laser spot is proportional to the expansion of piezo crystal inside the piezoactuator, we can find out the hysteresis curve by representing the data in Figure 3c in Figure 5a. The relation between hysteresis width and different voltage ranges is shown in Figure 5b, hysteresis width increases in the small voltage range because it is hard to find the position of the laser spot due to the rotation angle being too small. We can find that in this voltage range, the hysteresis width is small, which means the piezoelectric crystal behaves similarly as the voltage rises and falls.

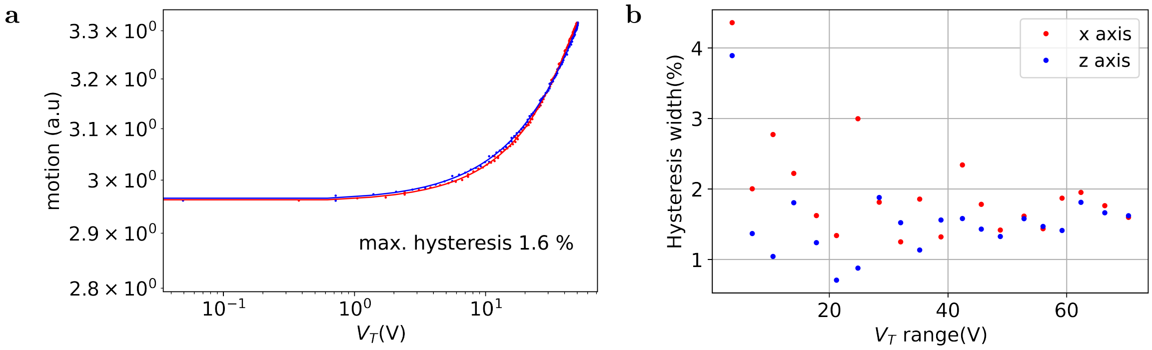

Figure 5: **a** The hysteresis curve when the input signal range is 5V. **b**. The relation between the width of hysteresis and the voltage range piezoactuator received

5 Conclusion

Now we can already change the course of the laser, and with some measurements, we have a better understanding of this piezoactuator. With the relation of rotation angle and voltage range, we can control the scope of scanning, and we also find the hysteresis width in this voltage range is small, which helps us to control the rotation more accurately. Next, it will be tested at the beamline.

References

[1] Description of the summer student program

[2] M. Lyubomirskiy & C. G. Schroer (2016) Refractive Lenses for Microscopy and Nanoanalysis, Synchrotron Radiation News, 29:4, 21-26, DOI: 10.1080/08940886.2016.1198670

[3] Piezoline-Piezosystem-Jena

[4] tilting system K-201-30

[5] Why your function generator outputs twice the programmed voltage