Driving a piezoelectric scanner

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1 Why measure capacitance

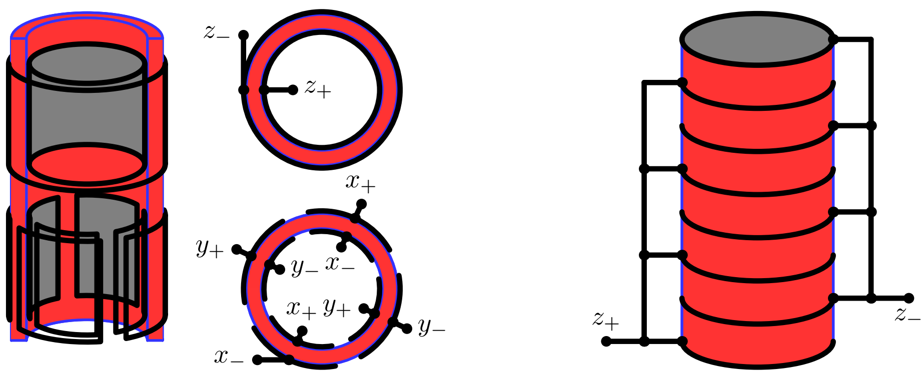

Figure 1: Tube- and stack-type piezo scanners[1].

A piezo tube scanner consists of a tube of piezoelectric material sandwiched between several electrodes (Fig. 1). With this configuration, the main issue in driving piezo movement is charging the capacitor.

The time constant τ for charging a capacitor C in series with a resistor R is given by

$$\tau = RC. \tag{1}$$

The capacitance between parallel plates of area A separated by a distance d is given by

$$C = \frac{\kappa\varepsilon A}{d}, \tag{2}$$

where κ is the dielectric constant of the material between the plates and ε is the permittivity of free space.

Because we expect small movements relative to the size of the piezo, we can expect that d remains relatively constant, so C will be roughly constant over our working range.

In order to estimate the charging time for an unstretched piezo, we need to measure the capacitance of the piezo scanner.

2 Measuring capacitance

As we do not seem to have a capacitance-measuring device in the lab, we will build one with our NI analog board[2].

2.1 False-starts

There are many complicated methods of accurately measuring impedance, but it seemed simple enough to just source an alternating current and measure the voltage induced over our piezo. For those whose E&M is rusty, the impedance of a capacitor X_C and inductor X_L are given by

$$X_C = \frac{1}{\omega C}, \qquad \text{and} \tag{3}$$

$$X_L = \omega L \tag{4}$$

respectively, where ω is the angular frequency.

I wrote a LabVIEW VI to measure capacitance by sourcing a driving current from our NI PCI-6052E board[2], but the sampling limit at 333kHz and the leakage capacitance and resistance of my voltage measuring leads limited the measurement to larger capacitances than I had available.

2.2 555 timer

I then wrote a LabVIEW VI to measure capacitance by watching the RC charging time for a capacitor and resistor in series, but again, the low impedance of the voltage-measuring leads limited the measurement to high capacitances.

I finally purchased some NE555N integrated circuits from Newark (SKU: 89K1486, $0.121), and following their suggested layout for monostable operation, generated a digital pulse with width 1.1τ [3]. The high impedance of the 555 chip allowed the use of the larger resistors needed for smaller capacitors. Using `meas_cap` to generate the trigger pulse and measure the width of the resulting pulse, I finally got accurate measurements for my test capacitors. Using 50 trials with a 1 MΩ resistor and a 100 kHz sampling rate, I measured my calibration capacitors at

Rated (pF)	Measured (pF)	± (pF)
0	16.7	0.1
390	425.9	0.1
1000	1008.8	3.0
1390	1413.6	6.0

I imagine my "390 pF" capacitor is actually around 415 pF, and my system is conservatively accurate to around 10%.

2.3 Capacitances of DI and Piezomechanik piezos

With the 555 timer setup, I measured the $X/Y/Z$ capacitances for E- and J-type scanners, yielding the capacitances listed in Table 1. The capacitance of stack piezos is much, much larger than tube piezos.

The pinouts for a DI piezo module are as follows (piezo cable is female micro DB-9, labeled from upper right, 1 2 3 4 5 / 6 7 8 9)[4]:

DB-25 Line	Piezo cable line	Color	Role
8	1	Black	Ground
-	2	-	Unused
-	3	-	Unused
18	4	Orange	(X+)
5	5	Yellow	(X-)
22	6	?Green?	(Z+)
Jumper 7	7	?Blue?	Substrate voltage
20	8	Purple	(Y+)
7	9	Grey	(Y-)

The wiring for a Piezomechanik piezo are as follows[5]:

Line	Color	Role
BNC	shield	Low voltage piezo contact
BNC	pin	High voltage piezo contact
Strain gauge	Red	
Strain gauge	Green	
Strain gauge	Black	
Strain gauge	White	

3 Charging a piezo

We need some estimate of R in order to calculate τ. R will either come from the internal impedance of our current source or from some external resistor to protect from excessive current. As a limiting case, the maximum rated current for the Nanoscope piezo control lines is 70 mA and the maximum rated voltage is ±220 VDC (Nanoscope IVa Controller Manual Rev. B, Chapter 10 "Access to Intermediate NanoScope IVa Signals", Table 10.2a "Signal Access Module Connector Ratings"). As luck would have it, the maximum rated average current for our power supply is also $I = 70$ mA.

A maximum current of $I = 70$ mA over a voltage range of $V = \pm 220$ VDC yields a minimum resistance of $R = V/I \sim 6.3$ kΩ to avoid over-current when jumping from one voltage rail to the other. With our Piezomechanic source, the voltage range is a unipolar $V = 150$ V, yielding a minimum resistance of $R = V/I \sim 2.1$ kΩ. However, since the τs are less than 200 ms, we are within the range of the "Current Booster", so we can use $I_B = 250$ mA, yielding $R_B =$ and $\tau_B =$. We use the unboosted current over 150 V to determine the Piezomechanic-sourced rail-to-rail τs and velocities given in Table 1.

Type	Axis	Capacitance (nF)	$\tau = R_{\text{series}}C$ (μs)	d_{33} (nm/V)	$v_{\max}$ (m/s)
DI E	X, Y	4.1	13		
DI E	Z	33	100		
DI J	X, Y	23	72		
DI J	Z	53	170	12.5	
Piezomechanik (small?)	Z	870	2700		
Piezomechanik (big?)	Z	2,300	7200		

Table 1: Measured capacitances (Sec. 2.3) and charging characteristics (Sec. 3) for various piezos in our lab. Charging times are for a resistively protected Piezomechanik source rounded to two significant figures. The d_{33} values are the manufacturer's ratings.

The J-type piezo is rated $d_{33} = 12.5$ nm/V, so it has a range of $\Delta z = 440\text{ V} \cdot d_{33} = 5.5\ \mu$m[6], giving a maximum pulling speed of $v = \Delta z/\tau = 9$ mm/s (Huge!).

Our current high voltage supply (Piezomechanik GmbH LE 150/025) has the following characteristics[7]:

Input:

Signal:	± 5 V
Impedance:	5 kΩ

Output:

Voltage total:	0 V thru +150 V
DC-Offset range:	0 V thru +150 V
Gain:	30 (without attenuation)
Peak Current:	250 mA (for 200 ms)
Average Current:	70 mA
Noise:	5 mVpp (for 2.7 μF load)

So we can certainly source enough current, and the internal output impedance seems to be in a safe range (no external resistor required). The "Monitor" output on the power supply mirrors the high-voltage output attenuated by a factor of 1000.

References

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