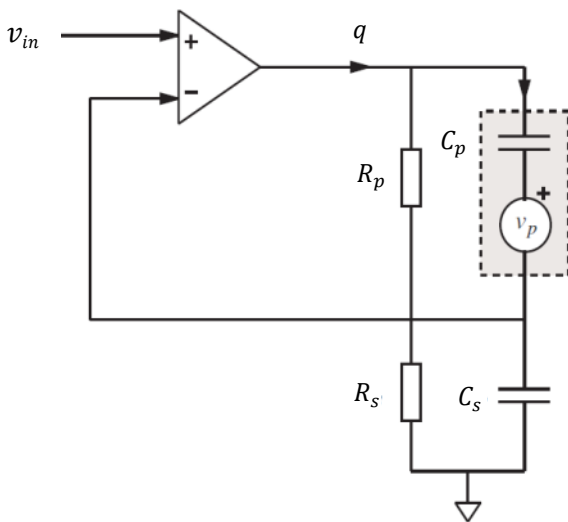


Introduction to Charge Drives

It has been known since the 1980's that piezoelectric transducers respond more linearly to current or charge rather than voltage [1]. However, problems with drift and the floating nature of the load have only been solved recently [2], [3]. Since then, charge drives have been demonstrated to reduce the hysteresis of piezoelectric actuators by up to 93% [4]. This corresponds to a maximum non-linearity of less than 1% which can reduce or eliminate the need for feedback or feedforward control in applications that do not require accurate positioning at frequencies below 1 Hz.

The simplified schematic diagram of a charge drive is shown below:



Simplified schematic diagram of a charge drive

The piezoelectric load, modeled as a capacitor C_p and voltage source v_p is shaded in gray. The high-gain feedback loop works to equate the applied reference voltage v_{in} to the voltage across a sensing capacitor C_s . Neglecting the resistances R_p and R_s , the charge q is

$$q = v_{in} C_s$$

That is, the gain is C_s Coulombs/V. This implies an input-to-output voltage gain of C_s/C_p .

A major problem with charge drives is the finite output impedance and dielectric leakage, modelled by R_p and R_s . These resistances cause the output voltage to drift at low frequencies. However, by setting the ratio of resistances equal to the ratio of capacitances, low-frequency error can be avoided. To maintain a constant voltage gain, the required resistance ratio is

$$\frac{R_p}{R_s} = \frac{C_s}{C_p}$$

The parallel resistances effectively turn the charge drive into a voltage amplifier at frequencies below

$$f_c = \frac{1}{2\pi R_p C_p} \text{ Hz}$$

Although the parallel resistances act to stabilize the voltage gain at low frequencies, the amplifier now operates as a voltage source below f_c and a charge drive above. A consequence is that reduction of non-linearity only occurs at frequencies above f_c . Practical values of f_c can range from 0.01 Hz to greater than 10 Hz.

The cut-off frequency f_c can be reduced by increasing the parallel resistances; however, a practical limit is imposed by the dielectric leakage of the transducer. In addition, excessively high resistance values also reduce the immunity to drift and result in long settling times after turn-on and other transient events. The settling time is approximately $5/2\pi f_c$ seconds.

An ideal compromise between excessively long settling times and good low-frequency performance is $f_c = 0.1$ Hz, implying a settling time of 8 seconds after turn-on. This value of f_c is adopted in the PDQ charge drives which have a cut-off frequency of between 0.03 Hz and 0.1 Hz, depending on the load capacitance.

PiezoDrive charge drives are designed for both high-performance and ease-of-use. Compared to a standard voltage amplifier, there is only one additional control, the DC-gain, which sets the voltage-gain at low-frequencies. The PDQ Charge Drives are preconfigured

during manufacture to drive a certain range of capacitance values. This means that the charge-gain, resistance ratios, and transition frequency f_c are all optimally preconfigured and do not require user adjustment. The standard capacitance ranges and the associated charge-gain, voltage-gain and cut-off frequencies are tabulated below.

Load Capacitance	Cut-off Freq.	Voltage Gain	Charge Gain
30 – 100 nF	0.3 – 0.1 Hz	66 – 22	2.2 uC/V
100 – 300 nF	0.1 – 0.03 Hz	60 – 20	6.2 uC/V
0.3 – 1.0 uF	0.1 – 0.03 Hz	66 – 22	22 uC/V
1.0 – 3.0 uF	0.1 – 0.03 Hz	60 – 20	62 uC/V
3.0 – 10 uF	0.1 – 0.03 Hz	66 – 22	220 uC/V

Load capacitance ranges of the PDQ drives

For ease-of-use, the PDQ drives are configured during manufacture for one of the load capacitance ranges in the above table. A smaller load capacitance is permissible but not recommended since the voltage gain and cut-off frequency will be excessively high. Load capacitances larger than the specified maximum are not possible. Always ensure the load capacitance is within the specified range before turning the drive on. The load capacitance range is printed on the back-panel of PDQ drives.

Example application

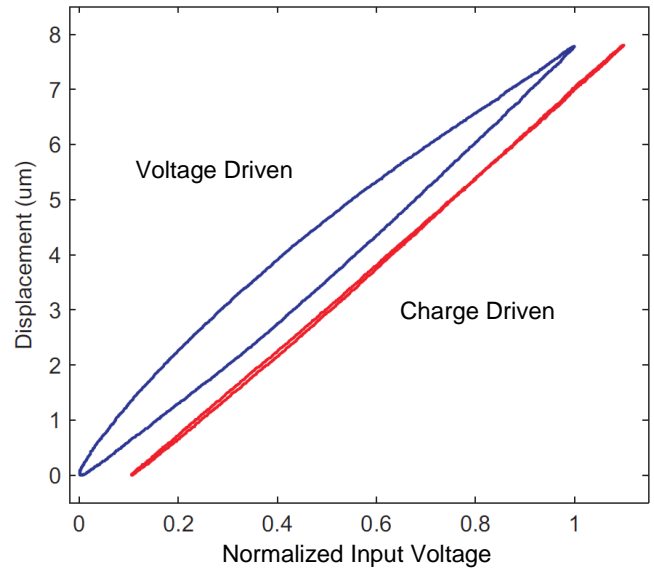
In this example, the response of a Noliac SCMAP07 piezoelectric stack actuator is compared when driven with a voltage amplifier and charge drive. The full displacement range of this actuator is 10.5 um at 200 V.

As the actuator capacitance is 330 nF, the 22 uC/V charge range was selected. This corresponds to a voltage gain of 66 and a cut-off frequency of 0.1 Hz.

The voltage- and charge-driven displacement responses to a 100-Hz 150-V sine wave are plotted below.

Using a voltage amplifier, the maximum difference in position between two points with the same applied voltage is 1.1 um, or 14.3% of the range. Alternatively, when the voltage amplifier is replaced by a charge drive, the non-linearity is reduced to 0.05 um or 0.65%

of the range. In many applications, this magnitude of non-linearity can avoid the necessity for feedback or feedforward hysteresis compensation.



Considerations when using a charge drive

In many respects, a charge drive is similar to a voltage amplifier; however, there are some important differences that should be considered:

The PDQ charge drives use a floating-load configuration as illustrated in the previous circuit diagram. In this configuration, the return signal path is not ground; rather it may float by up to 10 V. This means that the actuator load voltage is not simply the output voltage, but the difference between the output voltage and the return path.

It is also important to keep in mind that the return signal path is high-impedance. This means that any resistive or capacitive loads connected to the return path will cause an error. This includes multimeters, oscilloscopes, other instrumentation, and especially any ground connectors. The return path is also susceptible to electromagnetic interference so it should be kept well shielded.

The only connection to the output of a charge drive should be the actuator.

Low-Frequency Performance

The AC gain of a charge drive is C_s/C_p , however at frequencies less than f_c the gain is R_p/R_s . During calibration these gains are equalized, however this is only precisely true for the amplitude of the signal used for calibration. The use of different amplitudes may result in discrepancies between the AC and DC gain.

At frequencies close to the transition frequency f_c , the linearity degrades. For example, the linearity of a 60V stack actuator was measured to be +/- 1.7% at 10 Hz but this degrades to +/- 2.2% at 0.1 Hz.

Since creep occurs below the transition frequency, it is not improved by a charge drive. Hence, the open-loop drift of a charge driven actuator is similar to that of a voltage amplifier.

Contact

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