Quad Simulator Studies

- Mechanical Resonances
  - ANSYS Model
  - Data
  - Further Improvements
    - Adding 4th piezo
    - Low pass filter for drive signal

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Simulated by ANSYS 5.4 (Modal Analysis)

Original Config #1.
From ANSYS $f = 60\,\text{Hz}$

original Config #2.
From ANSYS $f = 310.21\,\text{Hz}$
Real Exp $f = 100\,\text{Hz}$
Some results

- Expected resonance $f_0 = 575 \text{ Hz}$
- Observed resonances at $70 \text{ Hz}$, $143 \text{ Hz}$, $175 \text{ Hz}$

Figure 5.3: Active stabilization system, consisting of a KZBE graphene on top of the magnet and a piezo actuator below it to tilt the quadrupole around its horizontal transverse axis. The length of the magnet is about 30 cm.

Figure 5.4: Schematic view of the active stabilization system.
Configuration of Piezos

Resonant Freq

![Graph showing resonant frequencies and configuration of piezos](image-url)
- Location of PiezoTranslator

Simulated by ANSYS 5.4 (Modal Analysis)

Case #1 \( f = 454.62 \text{ Hz} \)

Case #2 \( f = 457.33 \text{ Hz} \)

Case #3 \( f = 458.18 \text{ Hz} \)

Case #4 \( f = 461.69 \text{ Hz} \)
Case #5 \( f = 484.03 \text{ Hz} \)

Case #6 \( f = 326.66 \text{ Hz} \)

Case #7 \( f = 744.19 \text{ Hz} \)

Case #8 \( f = 774.41 \text{ Hz} \)
Without Filter;
100mV P-P
5Hz
driving signal
With Filter;
C=5uF, R=3300Ohm,
100mV P-P
5Hz

\[ T = RC = 1.65 \text{ msec} \]

\[ f_0 = \frac{1}{2\pi RC} = 96.46 \text{ Hz} \]
With Filter + base plate:

- \( R = 330 \, \text{Ohm} \)
- \( C = 5 \, \text{mF} \)
- \( 100 \, \text{mV P-P} \)
- \( 5 \, \text{Hz} \)

- \( Z = RC = 6.6 \, \text{msec} \)
- \( f_0 = \frac{1}{2\pi RC} = 24.11 \, \text{Hz} \)

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base plate

piezos
With Filter + 1 plate;
C=20uF, R=330 Ohm,
100mV P-P
5Hz
With Filter + 4 plate;
C=20uF, R=330 Ohm,
100mV P-P
5Hz
find $R_2' = 1.520 \, \text{k}\Omega$ and $R_2 = 10 \, \text{k}\Omega$. To satisfy the cutoff-frequency requirement, we have, from Eq. (16-29), $f_o = 1/2 \pi RC$. We arbitrarily choose a convenient value of capacitance, say, $C = 0.1 \, \mu\text{F}$ and find that $R = 1.6 \, \text{k}\Omega$. Figure 16-19 shows the complete fourth-order low-pass design.

The Butterworth filter possesses maximum flatness in the pass band, whereas a Chebyshev frequency-response characteristic possesses ripples (increases and decreases in gain) within the pass frequency range. However, the Chebyshev response has the sharpest cutoff characteristics of all filters. The design of a Chebyshev filter is carried out in the same manner as described above, except that a table of Chebyshev polynomials is used in place of Table 16-1.
where $P_n(s)$ is a polynomial in the variable $s$ with zeros in the left-hand plane. Active filters permit the realization of arbitrary left-hand poles for $A_V(s)$, using the operational amplifier as the active element and only resistors and capacitors for the passive elements. The fact that no inductors are required is an important advantage of practical filter design. The use of inductors should always be avoided, if possible, because they are bulky, heavy, and nonlinear; they generate stray magnetic fields; and they may dissipate considerable power.

Since commercially available OP AMPS have unity gain-bandwidth products as high as 100 MHz, it is possible to design active filters up to frequencies of several MHz. The limiting factor for full-power response at those high frequencies is the slew rate (Sec. 15-7) of the operational amplifier. (Commercial integrated OP AMPS are available with slew rates as high as 500 V/μs.)

**Butterworth Filter**

A common approximation of Eq. (16-22) uses the Butterworth polynomials $B_n(s)$ for $P_n(s)$, where the magnitude of $B_n(\omega)$ is given by

$$|B_n(\omega)| = \sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^{2n}}$$

(16-23)

The Butterworth response for various values of $n$ is plotted in Fig. 16-17. Note that the magnitude of $A_V$ is down 3 dB at $\omega = \omega_0$ for all $n$ and is monotonically decreasing. The larger the value of $n$, the more closely the curve approximates the ideal low-pass response of Fig. 16-20a on p. 586.

If we normalize the frequency by assuming $\omega_0 = 1$ rad/s, then Table 16-1 gives the Butterworth polynomials for $n$ up to 8. Note that for $n$ even, the
Summary

Set up with 3 piezos

\[ \text{ANSYS} \rightarrow \leq 330 \text{ Hz} \quad (\text{Rotation about x-axis}) \]

We measured 175 Hz

Upcoming Improvements

- Add 4\textsuperscript{th} piezo
- Implement 4\textsuperscript{th} order filter
- Use newly found configuration