Tomographic characterization of an atom trapping potential

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Motivation

Endgame: atom interferometry in highly-symmetric trap.

Classical Foucault pendulum primer:

- Plane of oscillation remains constant while the earth rotates underneath
- Essentially a rotation sensor
Atomic Foucault pendulum

It is possible to create an atomic Foucault pendulum with ultracold atoms in an ideal symmetric trap.
Sensitivity to asymmetries

- Small asymmetries in the trapping field obscures the Coriolis effect.

- Trap symmetry needs to be better than $\Delta \omega = 0.01 \text{ s}^{-1}$.
The atom trap

We trap $^{87}$Rb atoms in a magnetic time-orbiting potential (TOP) trap, giving the atoms a time-averaged shift in potential energy

$$U = -\mu_z \langle |B| \rangle$$

The field configuration includes an oscillating quadrupole field and rotating bias field,

$$\mathbf{B}_{\text{bias}} = B_0 \begin{bmatrix} \sin(\Omega_1 t) \cos(\Omega_2 t) \\ \sin(\Omega_1 t) \sin(\Omega_2 t) \\ \cos(\Omega_1 t) \end{bmatrix} \quad \mathbf{B}_{\text{quad}} = B_1' \cos(\Omega_1 t) \begin{bmatrix} x/2 \\ y/2 \\ -z \end{bmatrix}$$
Detection and correction

The spatial density of the atom cloud can be mathematically related to the potential by

\[ n(r) = n_0 \, e^{-\frac{U(r)}{kT}} = n_0 \, e^{-P(x, y)} \]

where \( P(x, y) \) is a polynomial parametrizing the potential,

\[ P(x, y) = \sum_{n, m} c_{nm} x^n y^m \]

The higher-order terms and cross terms can be changed by adjusting the magnitude of the bias fields and their relative phase.
Tomographic measurements

We image 2D slices of the atom trap.

- Load warm atom cloud (∼ 300 nK)
- Isolate horizontal plane of atoms with a “light blade” ($w_0 = 168 \, \mu m$, $z_0 \approx 1 \, m$)
- Capture fluorescence image of the slice
Method

After loading the warm cloud into the trap we selectively image part of the cloud:

1. Pump all atoms into $F = 1$
2. Reactivate 2D sheet of atoms back into $F = 2$
3. Probe cloud, causing only the reactivated atoms to fluoresce
Results

<table>
<thead>
<tr>
<th>Term</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x^2$</td>
<td>$1.73(6)$</td>
</tr>
<tr>
<td>$y^2$</td>
<td>$1.52(4)$</td>
</tr>
<tr>
<td>$xy$</td>
<td>$-0.04(3)$</td>
</tr>
<tr>
<td>$x^3$</td>
<td>$0.072(5)$</td>
</tr>
<tr>
<td>$y^3$</td>
<td>$0.025(3)$</td>
</tr>
<tr>
<td>$xy^2$</td>
<td>$-0.046(2)$</td>
</tr>
<tr>
<td>$x^2y$</td>
<td>$-0.091(6)$</td>
</tr>
<tr>
<td>$x^4$</td>
<td>$0.096(9)$</td>
</tr>
<tr>
<td>$y^4$</td>
<td>$0.06(2)$</td>
</tr>
<tr>
<td>$x^2y^2$</td>
<td>$0.008(7)$</td>
</tr>
<tr>
<td>$xy^3$</td>
<td>$-0.31(8)$</td>
</tr>
<tr>
<td>$x^3y$</td>
<td>$-0.03(8)$</td>
</tr>
</tbody>
</table>

Oscillation frequency changes with amplitude, showing anharmonicity of the trap for direct measurement and tomographic analysis.
Conclusions

- Tomographic imaging method is significantly faster than direct oscillation measurements.
- Apparatus drift needs to be fixed...
- Adding higher harmonic terms might be able to get at unwanted anharmonic terms.

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