Comment on "Direct Measurement of the Oscillation Frequency in an Optical-Tweezers Trap by Parametric Excitation"

In a recent Letter [1], Joykutty *et al.* claim to observe parametric resonance in an optical trap. They use the observation of a peak in the position variance of a trapped particle as a function of modulation frequency to give a new, precise method for calibrating trap stiffness.

We found this result extremely surprising. Intuitively, to show a resonant effect, the particle must "remember" its dynamics over at least one oscillation period. In the extremely overdamped conditions of an optical trap, the effects of any outside influence decay in a small fraction of a period, preventing the buildup of coherent motion, which must be present in order to affect the variance.

Although the discussion in [1] is qualitative and based on the behavior of the underdamped system, the solution to the Brownian parametric oscillator with arbitrary damping has been previously derived [2]. In the accompanying Comment, Pedersen and Flyvbjerg discuss in detail the overdamped limit and conclude that, indeed, there should be no finite-frequency peak in the position variance versus the trap modulation frequency [3].

To experimentally test these ideas, we repeated the experiment of Joykutty *et al.*, here modulating the laser power P by direct control of the laser current. We set the trap stiffness to be 9.27 pN/μm for a 3.17 μm polystyrene bead and measured the variance of the position from a 10 s time series sampled at 16 kHz at different modulation frequencies. Because of the long measurement time, the result may be affected by drift and ambient noise. In our experiment, we compensated for these effects by following each measurement with another where no modulation was present. We report the ratio of the two variances, σ_{xx}/σ_0, as a function of the frequency near twice the natural frequency ω_0, in Fig. 1. We see no sign of a resonance peak.

In response to a first version of this Comment, Venkataraman *et al.* [4] suggest that their observations could be explained by their use of an acousto-optic modulator (AOM) for varying the trap strength. They propose that the AOM modulates inadvertently either the beam position or the beam shape. However, neither effect leads to a variance peak. In modulating the laser-diode current, we also observed a periodic, linear shift in beam position. In the data reported in Fig. 1, we set our position-sensitive detector's axis normal to the beam-modulation direction. Because motion is linear for small modulations, the two axes are uncoupled, and we recovered the expected results. Analyzing the motion along the modulation direction, we saw an artificially increased variance because the trap drags the particle back and forth. But we observed no peak in variance at any finite frequency. Theoretically, a periodic shift in beam location can be accounted for by changing coordinates to $x_1(t) = x(t) - x_{\text{beam}}(t)$, where

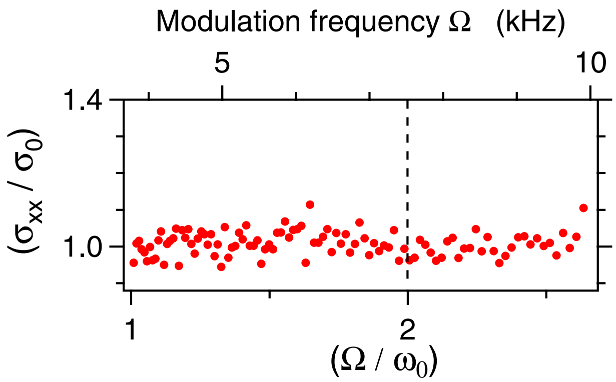

FIG. 1 (color online). Measured relative position variance.

$x_{\text{beam}}(t)$ is the time-dependent beam position. In the new coordinates $x_1(t)$, the modulation simply adds an ordinary inhomogeneous driving term. Since the oscillator is overdamped, no resonant response is expected. As for a modulation of the beam shape, since only the linear regime is probed, the effect can be simply absorbed into the overall magnitude of the modulation. [One expands $V(x) \approx V(0) + (1/2)V''(0)x^2$. Shape changes then modulate $V''(0)$ at lowest order, but that is exactly the same effect as changing the overall laser power.]

To conclude, our experimental evidence shows no peak in the variance, in contrast to the observations of Joykutty *et al.*. In addition, their proposed explanations that the effect is somehow linked to modulation of the beam position or shape can also be ruled out. Thus, we conclude that their observations are not due to parametric resonance and suggest that some other feature of their apparatus must be responsible for the data that they present.

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