Devil's Staircase in an Optomechanical Cavity

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Summary. We study self-excited oscillation (SEO) in an on-fiber optomechanical cavity [1]. While the phase of SEO randomly diffuses in time when the laser power that is injected into the cavity is kept constant, phase locking may occur when the laser power is periodically modulated in time. We investigate the dependence of phase locking on the amplitude and frequency of the laser power modulation (see Fig. 1). We find that phase locking can be induced with a relatively low modulation amplitude provided that the ratio between the modulation frequency and the frequency of SEO is tuned close to a rational number of relatively low hierarchy in the Farey tree (see Fig. 2). To account for the experimental results a one dimensional map, which allows evaluating the time evolution of the phase of SEO, is theoretically derived. By calculating the winding number of the one dimensional map the regions of phase locking can be mapped in the plane of modulation amplitude and modulation frequency. Comparison between the theoretical predictions and the experimental findings yields a partial agreement.

References

[1] H. Wang, Y. Dhayalan, and E. Buks, Physical Review E 93, 023007 (2016).

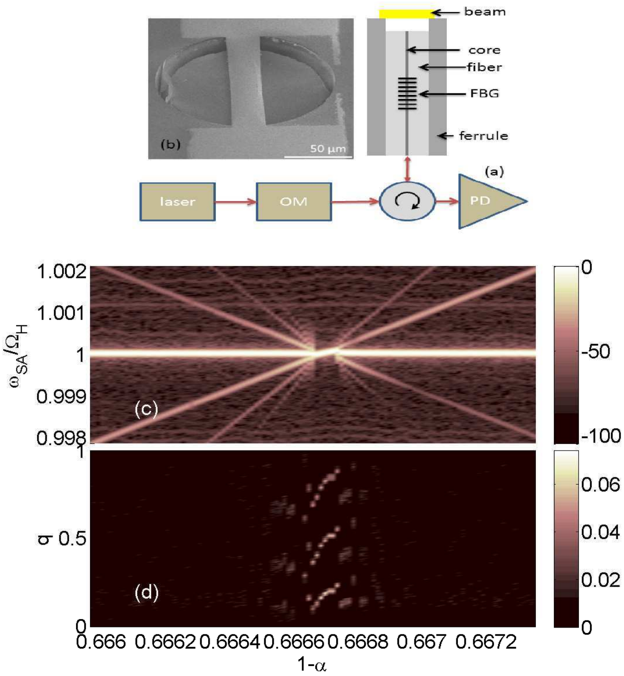

Figure 1: Experimental setup and phase locking. (a) A schematic drawing of the sample and the experimental setup. An on-fiber optomechanical cavity is excited by a tunable laser with external optical modulator (OM). The mechanical resonator has quality factor $Q = \omega_0/2\gamma_0 = 3800$ and the cavity has finesse $\beta_{\mathrm{F}} = 2.1$. The reflected light intensity is measured using a photodetector (PD), which is connected to both a spectrum analyzer and an oscilloscope (not shown in the sketch). (b) Electron micrograph of the suspended micromechanical mirror, whose mass is $m = 1.1 \times 10^{-12}$ kg. (c) Spectrum analyzer signal in dB units vs. normalized modulation frequency $1-\alpha$ and normalized measurement frequency $\omega_{\mathrm{SA}}/\Omega_{\mathrm{H}}$. In a region near the point $1-\alpha = 2/3$ entrainment occurs. The average laser power is set to $12\,\mathrm{mW}$, the wavelength to $\lambda = 1545.498\,\mathrm{nm}$ and the dimensionless modulation amplitude to $\beta_{\mathrm{f}} = 0.025$. (d) The measured probability distribution $F(q)$ of the relative phase q vs. $1-\alpha$. In the same region where entrainment occurs [see panel(c)] the distribution $F(q)$ is peaked near three values [see panel (d)].

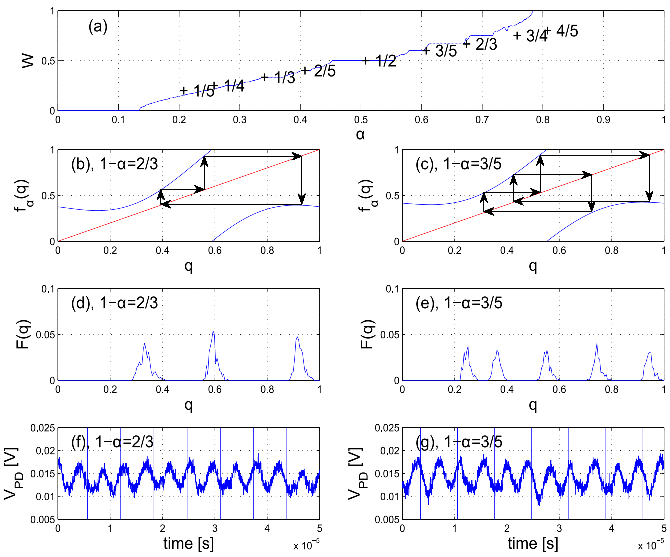

Figure 2: The winding number and limit cycles. (a) Devil's staircase in the plot of the winding number W vs. α for the case where $\beta_{\mathrm{f}} = 0.0355$. Locally stable limit cycles for the case $1-\alpha = 2/3$ and $\beta_{\mathrm{f}} = 0.025$ are presented in panels (b), (d) and (f) and for the case $1-\alpha = 3/5$ and $\beta_{\mathrm{f}} = 0.028$ in panels (c), (e) and (g). The map $f_\alpha(q)$ together with the corresponding limit cycle for the case $1-\alpha = 2/3$ $(1-\alpha = 3/5)$ is depicted in panel (b) [panel (c)], the experimentally measured probability distribution $F(q)$ in panel (d) [panel (e)], and a sample temporal data in panel (f) [panel (g)] (the vertical lines label the beginning points of each modulation period). In the experimental measurements presented in this plot a pulse power modulation having a rectangular (instead of a sinusoidal) waveform has been employed.