

Lyapunov-based cooling of mechanical oscillator with arbitrary frequency

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Abstract

We propose a cooling scheme to break the oscillator cooling limit by an extra control field which is designed by using optimized Lyapunov control theory. The results show that an ultraefficient cooling process can be realized in our model without any limitation of the parameters. Both the cooling model and the control field can be achieved by experiment easily. Our results also provide a promising platform for the observation of mesoscopic quantum effect and precision probe.

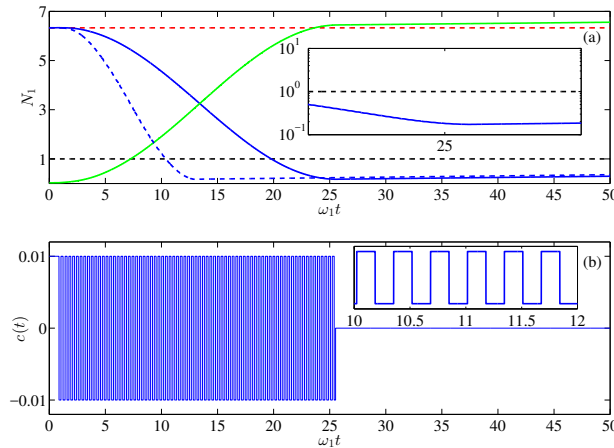


Figure 1: (a): Phonon number evolutions of target oscillator (blue) and auxiliary oscillator (green). The dotted lines denote the steady state cooling limit of the target oscillator (red) and 3dB limit (black), respectively. (b): Control field as a function of time t . The inset shows the local amplification of time of $c(t)$. Here we set $\sqrt{W}/\omega_1 = 0.1$ (blue, solid).

we proposed and analyzed a cooling scheme to break the cooling limit, and we found that an arbitrary oscillator (even having a small frequency and low Q -factor) can be deep into the quantum regime from room temperature with the help of an auxiliary dynamic dissipative cooling system. By using Lyapunov control theory, we give the concrete form of control field after simulations. The results show that the control field in this model is a square wave without high frequency oscillation. It can be realized easily by adding a square wave voltage to the LC oscillator system[1][2]. Under this control field, the minimum phonon number of the target oscillator can be reduced to $N_1 = 0.174$, from the fig which is only 3% of the cooling limit. The optimized Lyapunov control field ensures that the target oscillator can be cooled to this minimum phonon number quickly, which also reduces simultaneously the heating effect of the environment effectively. We also find that the quantum cooling limit is also be broken by setting $n_{th} = 0$. Compared with the existing quantum cooling methods which can also breakthrough the cooling limit, our protocol has the following advantages: (i). Unlike non-Markovian dissipative cooling, the Lyapunov control can ensure that the “classical” part of the system is still in an asymptotic steady state, which means that the classical phonon number ($\langle \hat{b}^\dagger \hat{b} \rangle - \langle \hat{b}^\dagger \hat{b} \rangle$) can be considered as a potential energy shift and we do not need other mechanism to restrict it. (ii). The control field can adjust the BS process and the parametric process automatically. Therefore, the rotating wave approximation is not necessary here and the parameter constraints are further relaxed because we do not need to satisfy RWA condition. (iii). The optimized Lyapunov control does not need auxiliary oscillator re-coupling to the optical field. To sum up, we believe our scheme can provide a promising platform for the observation of mesoscopic quantum effect and precision probe.

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[2] T. A. Palomaki, J. W. Harlow, J. D. Teufel, R. W. Simmonds, and K. W. Lehnert, *Nature*, **495**, 210 (2013).