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Preservation of coherence for a two-level atom tunneling through a squeezed vacuum with finite bandwidth

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ABSTRACT

Tunneling of a two-state particle through a squeezed vacuum is considered. It has been shown that repetitive measurement or interaction with the external field can preserve the coherence. Moreover, the coherence time in terms of the squeezing parameters has been calculated. A specific condition is derived, under which the coherence is sustainable.

1. Introduction

Starting from quantum computation to various other aspects, the ability to preserve coherence in quantum systems is of fundamental importance with many useful consequences. But in practical situations, quantum mechanical systems are extremely vulnerable to environmental interactions, leading to the loss of coherence in a very short period of time. The process of this breaking up of quantum superposition is known as the phenomena of decoherence [1]. Developing techniques to preserve quantum coherence is an emergent area of research nowadays from both theoretical and experimental point of view. The spin echo and multiple pulse techniques in NMR [2,3], dynamical decoupling methods for open quantum systems [4,5], are the examples of some versatile tools for controlling decoherence. Environment in the form of some external fields plays the role of reservoir in open quantum systems. Sometimes squeezed vacuums can also assume the role of the reservoir [6–8]. Though the properties of such reservoirs are different. It is a quite well-known fact that squeezed vacuum can

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have considerable effects on quantum dissipative processes [9]. Particularly, when a two-state atomic system interacts with a broadband squeezed vacuum, the transverse polarization quadratures exhibit decay processes, though different from the usual quantum decays [6]. In this work, we have considered a system of two-level atom tunneling through a squeezed vacuum with finite bandwidth. Our goal is to investigate the possibilities of sustainable quantum coherence within the period of dwelling through the vacuum region.

In the first part, we will calculate the coherence time and the dwell time [10] for the system and compare the two timescales. The ratio of these two timescales is considered as a measure of sustainable coherence within the period of tunneling through the vacuum. If the coherence time is longer than the dwell time (i.e. the ratio is greater than unity), then it can be said that quantum coherence is sustainable for at least the period of tunneling through the barrier. From our result, it will follow that repetitive measurement is one particular condition, under which we can achieve sustainable coherence. In the second part of our work, we will consider the master equation for the system coupled to the squeezed bath, from which we will derive the decay parameter for the particle under the steady-state scenario. Considering this decay dynamics, we will then formulate the coherence time for the particle tunneling through the vacuum. We will see that this timescale is dependent on the system frequency as well as a number of bath parameters, leading to a specific condition under which the coherence of the system is sustainable. In Section II, we will discuss the aspect of coherence control through repetitive measurement and see that how Zeno dynamics can play an important role in sustaining the quantum coherence of the system. Then in Section III, we will consider the master equation approach for a two-state system tunneling through a squeezed vacuum and derive the coherence time. After that we will conclude with some possible implications.

2. Preservation of coherence by repetitive measurement

Let us now start with the concept of degree of coherence, which is a certain measure of the amount of coherence for the system in concern. Since, in this work, we are dealing only with the time evolution of the system, we will consider the degree of temporal coherence, which is given by the expression

$$g(\tau) = \frac{G(\tau)}{G(0)} \tag{2.1}$$

where $G(\tau)$ is the coherence function given by

$$G(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} U_s^*(t) U_s(t+\tau) dt \tag{2.2}$$

where $U_s(t)$ is the time evolution operator of the system given by

$$U_s(t) = \exp[i\alpha t - \Gamma t] \tag{2.3}$$

Γ is the decay parameter, which we will evaluate in later course. Using the expression of $U_s(t)$, we can get from Eq. (2.2)

$$G(\tau) = \lim_{T\to\infty} \frac{\sinh(2\Gamma T)}{2\Gamma T} \exp[i\alpha\tau - \Gamma\tau]. \tag{2.4}$$

So the degree of coherence is found to be

$$g(\tau) = \exp[i\alpha\tau - \Gamma\tau]. \tag{2.5}$$

The coherence time for the system can be calculated as

$$\tau_C = \int_0^\infty |g(\tau)|^2 d\tau = \frac{1}{2\Gamma}. \tag{2.6}$$

Now let us derive the expression of dwell time for our concerning system in the framework of weak measurement. Weak measurement of a certain operator [11–13] is the process of measurement