Optik 126 (2015) 2018–2021

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Effect of the optical field in squeezed coherent state on the entanglement of coupling qubits

Yangde Fang*

Shangrao Radio & TV University, Shangrao, 334000, China

ARTICLE INFO

Article history:
Received 2 April 2014
Accepted 17 May 2015

Keywords:
Squeezed coherent state
Coupling qubits
Entanglement
Probability

ABSTRACT

We investigate the interaction between the optical field in squeezed coherent state and the coupling qubits. By means of numerical calculation, we discuss the effects of coherent amplitude, relative phase of the coupling qubits, squeezing parameter and azimuth angle on the concurrence and the probability of two qubits simultaneously in the excited state. When the relative phase is zero, entanglement death will occur, which can be avoided through increasing the relative phase. Larger value the relative phase takes, more the concurrence will be far away from entanglement death. Moreover, smaller squeezing parameter will also help to entanglement maintaining. The research indicates that in the optical filed of squeezed coherent states, the entanglement death can be avoided completely through manipulating the relative phase of the coupling qubits that initially in the entangled coherent states.

© 2015 Elsevier GmbH. All rights reserved.

1. Introduction

Circuit quantum electrodynamics (circuit–QED) that is based on the coupling between the superconducting transmission line and the qubits has become a popular physical system in solid quantum information owing to its good quantum coherence and integration. It also provides an ideal experimental platform for the research of quantum measurement and quantum control [1–4]. Circuit–QED system can be considered as the solid counterpart of the atom-based optical cavity–QED, namely, the Josephson junction based qubit is corresponding to the artificial atom, and the superconducting transmission line acts as the optical microcavity [5]. As a valid way for quantum calculation, cavity–QED mainly focuses on the coupling properties between the atom and the independent photon in the cavity with high quality factor. The structure of circuit–QED can separate the qubit from interacting with the electromagnetic environment, realize non-destructive readout of multi-photon with high precision, and form to the state of microwave photon field that suitable for quantum calculation. This kind of circuit structure provides a simple and effective approach for solid quantum calculation and opens a new way for macroscopically researching entanglement state and quantum measurement, based upon which much important progress has been made recently. For instance, the particle-like feature of the microwave photon has been observed [6]; the single photon state, binomial state and Fock state are generated [7–9]; the Berry phase is observed [10]; the artificial single atom laser is realized [11]; the fundamental quantum limit of quantum measurement and decoherence is investigated; the effective coupling between two qubits induced by microwave photons, the operations of fundamental quantum logic gates, and so on [12].

In the past few decades, one of the most important developments in quantum optics is constructing many optical nonclassical states in different quantum system, the squeezed coherent state among others [13,14]. As a typical nonclassical state, the squeezed coherent state possesses two extremely important nonclassical features, one of which is the quantum characteristic that the quantum fluctuation of one orthogonal component in the squeezed coherent field is less than that in the coherent field, the other is statistical property that the number of photon obeys sub-Poisson distribution and reveals the antibunching effect of the photons when the squeezing factor indicating the squeezing extent in the squeezed coherent state is greater than zero. There are valuable applications in precise measurement and computation, optical communication, detection of gravitational waves and quantum nondestructive measurement for the two nonclassical features of the squeezed coherent state. The preparation of the squeezed coherent state has been implemented experimentally in the oscillator system and so forth [15].

One of the most striking features of quantum mechanics is the concept of entanglement. An entangled state is the state of a composite system that cannot be separated into product states in terms

---

* Tel.: +0086 07938392996.
E-mail address: fyd8006@163.com

http://dx.doi.org/10.1016/j.ijleo.2015.05.067
0030-4026/© 2015 Elsevier GmbH. All rights reserved.

of subsystems. Entanglement is a quintessential property of quantum mechanics that sets it apart from any classical physical theory. An important feature of entanglement is that it gives rise to correlations that cannot be explained by any local realistic description of quantum mechanics. Therefore, quantum entanglement is a nonlocal quantum connection. It is not only a powerful tool for testing the basic problems of quantum mechanics, but also a physical foundation for future quantum information science.

It is well known that one needs sustained entanglement between the qubits as they dynamically evolve in time for many applications of interest. Indeed, quantum entanglement has become an important physical resource for quantum communication and information processing like universal geometric quantum gates [16], quantum teleportation [17], superdense coding [18], quantum key distribution [19]. Quantum properties, however, are very fragile. Under the influence of a pure dissipative environment in particular, a mixed state of an initially entangled two-qubit system becomes completely disentangled in a finite time. This is called entanglement sudden death (ESD) which has been observed in two elegantly designed experiments with a photonic qubit and atomic ensemble [20]. In order to ensure the realization of correct computing of quantum logic, people have undertaken a lot of studies on ESD phenomena, including not only how to avoid ESD but also how to restore entanglement in the two-qubit system [21,22].

The investigation on quantum characteristics in the interacting system between circuit–QED and coupling qubits has become frontier research topics in the cross field of quantum optics and quantum information. Studies have been dedicated to examine the interaction between the circuit–QED in general coherent state and the coupling qubits. However, the research involving the effect of microwave field in squeezed coherent state on quantum entanglement is seldom reported. In the present work, using the circuit cavity model which is constructed by coupling two superconducting charge qubits via a big Josephson junction, we investigate the interaction between the optical field in squeezed coherent state and the coupling superconducting qubits. By means of numerical calculation, we discuss the effects of coherent amplitude, relative phase of coupling qubits, squeezing parameter and azimuth angle on the concurrence and the probability of two qubits simultaneously in the excited state.

The rest of this paper is organized as follows. In Section 2, we show the outline of the theoretical approach used in the present work. The effects of the parameters of the optical field on the concurrence and the probability of two qubits simultaneously in the excited state are examined in Section 3. In Section 4, the obtained results are summarized and discussed.

2. Model

We model a big Josephson junction as data bus and couple two superconducting charge qubits through it, which is described in Ref. [23]. When the dc biased magnetic field Φ_e is externally applied, the Hamiltonian for the system is given by

$$H = \sum_{k=1}^{2}\left[E_k(V_{xk}) - 3E_{Jk}\cos\left(\frac{\pi\Phi_e}{\Phi_0} - \frac{\gamma}{2}\right)\cos\varphi_k\right] - E_{J0}\cos\gamma \qquad (1)$$

$E_k\left(V_{xk}\right) = E_{Ck}\left(n_k - C_kV_{xk}/2e\right)^2$ is the electrostatic energy of charge qubits, $E_{Ck} = 2e^2/\left(C_k + 2C_{Jk}\right)$ and E_{Jk} is the charging energy and Josephson energy of kth qubit, and E_{J0} is the Josephson energy of the big junction. Exerting a time-variant microwave field, the manipulation for both single qubit and coupling qubits could be achieved through controlling amplitude modulation or frequency modulation. We focus on how the microwave fields in squeezed coherent state affect the entanglement of coupling qubits, where the superconducting qubits are placed inside microwave field.

Considering the situation of quantization microwave field $\Phi_q a^+ + \Phi_q^* a$, Φ_q is the amplitude and $a^+\left(a\right)$ is the creation and annihilation operator. After some calculations, the interactive Hamiltonian between the quantized magnetic field and two superconducting charge qubits can be written as

$$H_I = g\left(a^+\sigma_1^-\sigma_2^- + a\sigma_1^+\sigma_2^+\right) \qquad (2)$$

$$g = -\frac{\Phi_q I_{C1} I_{C2}}{I_0}\sin\left(\frac{2\pi\Phi_e}{\Phi_0}\right). \qquad (3)$$

I_0 and I_{ck} are the critical current of the large junction and kth superconducting qubit. We suppose that the two superconducting qubits are in the Bell state with spins anti-correlated,

$$\left|\psi_Q\left(0\right)\right\rangle = \cos\theta\left|gg\right\rangle + e^{i\varphi}\sin\theta\left|ee\right\rangle \qquad (4)$$

and the cavity field is initially in a squeezed coherent state

$$\left|\psi_F\left(0\right)\right\rangle = \sum_n f\left(n\right)\left|n\right\rangle \qquad (5)$$

$$f(n) = \frac{1}{\sqrt{n!\cos hr}} \times \left(\frac{1}{2}e^{i\chi}\tan hr\right)^{n/2} \exp\left[-\frac{|\alpha|^2}{2} + e^{-i\chi}\frac{\alpha^2}{2}\tan hr\right] H_n\left(\frac{\alpha}{\sqrt{2e^{i\chi}\sin hr \times \cos hr}}\right) \qquad (6)$$

where $\alpha = \sqrt{\bar{n}}e^{i\delta}$ is the coherent amplitude component, $\bar{n}, r$ denotes the average number of photons and the squeezing parameter, respectively. In the interaction picture, we write the system's vector at any time t as [24,25]

$$\left|\psi\left(t\right)\right\rangle = \sum_{n=0}^{\infty}\left[x_n(t)\left|e,e,n\right\rangle + y_n(t)\left|g,g,n+1\right\rangle\right] + f\left(0\right)\cos\theta\left|g,g,0\right\rangle \qquad (7)$$

where

$$x_n(t) = e^{i\varphi}f(n)\sin\theta\cos\left(\sqrt{n+1}gt\right) - f(n+1)\cos\theta\sin\left(\sqrt{n+1}gt\right),$$

$$y_n(t) = e^{i\varphi}f(n)\sin\theta\sin\left(\sqrt{n+1}gt\right) + f(n+1)\cos\theta\cos\left(\sqrt{n+1}gt\right).$$

Entanglement plays an important role in quantum computation and quantum information, which is a kind of nonclassical correlation that is not available in classical world. Quantum information transmission depends on the entanglement features between qubits. We adopt the concurrence defined by Wootters [26] to measure the system entanglement. One can calculate the concurrence for the initial states $\left|\psi\right\rangle$ as

$$C\left(t\right) = 2\left|\sum_{n=0}^{\infty}x_{n+1}\left(t\right)y_n^*\left(t\right) + x_0\left(t\right)f^*\left(0\right)\cos\theta\right|. \qquad (8)$$

In order to comprehend in depth the dynamical evolution of the entanglement for the coupling qubits in squeezed coherent state, we investigate the probability of two qubits simultaneously in the excited state which is given by

$$P_{ee} = \left\langle ee\right| Tr_{field}\left(\left|\psi\left(t\right)\right\rangle\left\langle\psi\left(t\right)\right|\right)\left|ee\right\rangle \qquad (9)$$

Download English Version:

https://daneshyari.com/en/article/848109

Download Persian Version:

https://daneshyari.com/article/848109

Daneshyari.com