Quantum phase diffusion of a Bose system: beyond the Hartree-Fock-Bogoliubov approximation

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Bose-Einstein condensation (BEC) of weakly interacting atom systems has attracted large attention since the studies on liquid Helium, and a renewed interest stimulated by experimental observations of condensation of trapped alkali atoms. The condensate is usually considered in a coherent state whose amplitude satisfies a nonlinear Schrodinger equation. Quantum fluctuations determine the instability of this state, known as phase diffusion (PD). This instability is expected in systems in restricted geometries, where a symmetry-breaking phase cannot occur. A gapless approximation, the Bogoliubov or the Hartree-Bogoliubov (HB), has been shown to exhibit PD, but it is has also been noted that a complete self-consistent approximation, the Hartree-Fock- Bogoliubov (HFB), has a gapped spectrum which prevents PD. The drawback is that HFB does not satisfy the number conservation law. The aim of this work is to show that a gapless self-consistent approximation can be introduced which satisfies the number conservation law. The result is achieved within a truncation procedure of the equations of motion which considers linear and bilinear quantities in the boson creation and annihilation operators space. Higher order terms are taken into account by means of the factorization in the original picture of creation and annihilation particles operators, or alternatively, by normal ordering of corresponding quantities in the quasi- particle operators.