Quantum Metrology Beyond Heisenberg Limit with Atomic Bright Soliton Josephson Junctions in the Presence of Losses

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The measurement and estimation of chosen physical parameters with Heisenberg sensitivity and beyond are one of the challenging problems for current quantum metrology. We have shown that quantum matter-wave solitons possess Heisenberg ($1/N$) and super-Heisenberg ($1/N^3$) scaling levels for the estimation of some solitons parameters in the framework of linear and nonlinear metrology approaches, respectively; N is particle number involved in the measurement scheme [1]. We offer a novel soliton Josephson Junction (SJJ) system, which provides the formation of the entangled Fock (N00N-like) state as the probe. We studied some remarkable features of the superfluid-Mott insulator quantum phase transition, which occurs in such a system for experimentally accessible soliton parameters. In particular, the full quantum analysis demonstrates an abrupt transition to the superposition of entangled Fock states due to particle dependence of the tunnelling rate, cf. [2]. We have shown that the obtained quantum state is more resistant to few particle losses from the condensates if tiny components of entangled Fock states are present in the vicinity of the major N00N-state component. By examining quantum Fisher information (QFI), we have shown that operating near the quantum phase transition point helps to sustain the accuracy of the phase estimation even in the presence of moderate particle losses. We demonstrated that such states are close to the optimal ones obtained numerically by means of the optimization problem for QFI. Our results contribute to further improvement of the current experiments performed with atomic condensate solitons containing a mesoscopic number of particles.

References

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