Semi-classical potential for quantum annealing with antiferromagnetic fluctuation

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We see the quantum annealing (QA) process by evaluating the semi-classical potential on the basis of the spin-coherent state. QA is developed for efficiency solving a problem such as a combinatorial optimization by finding a ground state of a final target Hamiltonian. QA is accomplished by varying Hamiltonian from a trivial one $\hat{H}_i$ to a target one $\hat{H}_f$ such as

$$\hat{H}(s) = (1-s)\hat{H}_i + s\hat{H}_f \ (0 \leq s \leq 1), \tag{1}$$

where s is a time evolution parameter. In Ref. [1], Farhi and his colleagues proposed the detour paths instead of the straight path from initial to final Hamiltonian such as

$$\hat{H}(s) = (1-s)\hat{H}_i + s\hat{H}_f + s(1-s)\hat{H}_e, \tag{2}$$

where $\hat{H}_e$ is a extra Hamiltonian to trace the detour paths. They showed that the detour paths contribute to find the ground state correctly under the certain Hamiltonian such that we can not reach the ground state without the detour paths. Noting that they evaluate the semi-classical potential for the Hamiltonian to see the capability of the detour paths, and the potential clearly supports their conclusion. Also in other studies [2–5], the spin-classical potential is used validly.

In present study, we focus on the ferromagnetic p-spin model which can be reduced to Glover problem for $p \to \infty$. In Ref. [6], the antiferromagnetic fluctuation (AFF) is additionally introduced to the Hamiltonian (1) as follows

$$\hat{H}(s,\lambda) = s\{\lambda\hat{H}_f + (1-\lambda)\hat{V}_{\mathrm{AFF}}\} + (1-s)\hat{H}_i. \tag{3}$$

Here, $\hat{V}_{\mathrm{AFF}}$ denotes AFF and λ is another time evaluation parameter. This Hamiltonian is proposed for avoiding the first-order transition which causes an inefficiency of QA for the p-spin model clamed in Ref. [7]. Actually, they have proven that AFF works well. Although the concepts of the Hamiltonian (2) and (3) are similar, their background are not same. We see such physics of the Hamiltonian (3) by considering the semi-classical potential. Consequently, the semi-classical potential allows us to intuitively confirm that AFF contributes to avoid the first-order transition and generates the second-order transition.

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