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ABSTRACTS

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Implementation of adiabatic clustering quantum algorithm on system of five spins *S* = 1

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Currently, the efforts of many scientists are aimed at creating quantum computers. Great progress has been made in the construction of so-called NISQ-era devices [1] (Noisy Intermediate-Scale Quantum). NISQ-computers will not be protected by quantum error correction, and noise severely limits the scale of computations. To reduce the number of controlled elements, we can move from qubits to qutrits (spins S = 1), and use adiabatic quantum computation to improve noise immunity. In this work we consider clustering a set of six points into three groups. Clustering is partitioning a set data points into subset in according to proximity of their properties (in our case according to distances between two points on Cartesian plate). At initial moment of time, system is prepared in the ground state of initial Hamiltonian – Hamiltonian of interaction with a transverse magnetic field. Then the Hamiltonian adiabatically changed in time (in the discrete-time approximation) to the final Hamiltonian, in the ground state of which we encode the solution of the problem [2]:

$$H_P = \sum_{i\neq j}^{5} R_{ij}\left(S_i^z S_j^z + 3S_i^z S_i^z S_j^z S_j^z - 2S_i^z S_i^z - 2S_j^z S_j^z + 1\right) + \sum_{j=1}^{5} R_{0j}\left(S_j^z + S_j^z S_j^z - 1\right),$$

where R_{ij} is distance between data points i and j, S_j^α is projection operator of spin j on axis $\alpha \in \{x, y, z\}$. For realization the algorithm on a physical system the interaction in the Hamiltonian H_P should be expressed with dipole-dipole and Zeyman interactions. Effective Hamiltonian H_P is implemented with selective radiofrequency (RF) pulse [2]:

$$H_{pulse} = \sum_{j=1}^{5}\left(\omega_j - \omega_{rf}\right)S_j^z + \sum_{j=1}^{5} Q_j\left[3\left(S_j^z\right)^2 - 2\right] + H_{dd} + h_{pulse}\sum_{j=1}^{5}\left(S_j^x\cos\varphi - S_j^y\sin\varphi\right),$$

where ω_j is Larmor frequency of spin j, Q_j is quadrupole constant, ω_{rf} is frequency of attached RF pulse, which determines the selectivity of the attached impulse: $\omega_{rf} = \omega_j^{1\leftrightarrow 2} = E_j^1 - E_j^2 = -3Q_j + \omega_j$ for the transition between levels 1 and 2 of spin j, and for the transition between levels 2 and 3: $\omega_{rf} = \omega_j^{2\leftrightarrow 3} = E_j^2 - E_j^3 = 3Q_j + \omega_j$., $H_{dd} = \sum_{i\neq j}^{5} J_{ij} S_i^z S_j^z$ is Hamiltonian of dipole - dipole interaction, h_{pulse} is amplitude of attached pulse, φ is phase of attached pulse. This pulse implement rotation $\{\theta\}_{\alpha,i}^{k\leftrightarrow n} = \exp\left[-it_{pulse}H_{pulse}\right]$, which change population of level *k* and *n*, where t_{pulse} is pulse duration, $\alpha \in \{x, y\}$. The phase shift operators $\{\theta\}_{z,i}^{k\leftrightarrow n}$ can be obtained in two ways: a) $\{\theta\}_{z,i}^{k\leftrightarrow n} = \{-\pi/2\}_{y,i}^{k\leftrightarrow n} \cdot \{\theta\}_{x,i}^{k\leftrightarrow n} \cdot \{\pi/2\}_{y,i}^{k\leftrightarrow n}$, b) by setting up phases of subsequent pulses at this transition. In order to minimize the error, h_{pulse} must be small to avoid cross-talk noise. To avoid a phase error, t_{pulse} should be multiple $2\pi/\omega_j$ и $2\pi/Q_j$ [2]. We find the amplitudes and durations of rectangular RF pulses, as well as the durations of free evolution intervals in the control pulse sequence, and performed numerical simulation. Also we studied the dependence of the implementation fidelity on the parameters. We took quadrupole nuclei as qutrits, but the results obtained will be useful for controlling quantum processors based on qutrits represented by other systems.

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1. J. Preskill.”Quantum Computing 40 years later”. arXiv:2106.10522v3, 2023.
2. I. S. Pichkovskiy and V. E. Zobov. “Clustering into three groups on a quantum processor of five spins S=1, controlled by pulses of resonant RF fields”, Appl Magn Reson, **54**, pp. 661-677, 2023.