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Investigation and optimization of the continuous and discrete heat exchangers in the mK dilution refrigerator for cooling superconducting quantum chips

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The recent decade has witnessed the rapid development of superconducting quantum computing for its ultra-fast execution speed. The quantum chips should operate at a temperature below 20 mK, which poses a significant challenge for the suitable cryogenic system. The dilution refrigerator which can not only operate continuously and stably but also features with the merits of low vibration and electromagnetic interference has become an indispensable cryogenic technology for it. Unlike other refrigerators in ultra-low temperatures, there are two types of heat exchangers in the dilution refrigerator due to the effect of Kapitza resistance, including the continuous and discrete heat exchangers. Both of them are decisive factors because their flow and heat transfer characteristics play an important role in determining the cooling performance. In this paper, a numerical model of both the continuous and discrete heat exchanger is established, based on which the effects of working conditions (inlet pressure, temperature, etc.) and structure parameters (tube diameter, length, particle size, etc.) on the heat transfer coefficient are simulated. In addition, the coupling between each stage of the heat exchanger is also investigated to optimize the cooling performance of the dilution refrigerator. The theoretical analysis and simulation results will be discussed in detail, and the effect of the coupling relationship on the performance of the dilution refrigerator will be presented. It is indicated that the designed heat exchangers are quite helpful for optimizing the cooling performance of dilution refrigerators.

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