**REVIEW**

Of the PHD thesis

for obtaining the educational and scientific degree “Doctor”

in professional field 4.1 Physical sciences

on defense procedure at the Faculty of Physics

of Sofia University “St. Kliment Ohridski”

The review is prepared by Assoc. Prof. Peter Aleksandrov Ivanov, SU "St. Kliment Ohridski", Faculty of Physics, in his capacity as a member of the scientific jury according to Order NRD38-321/06.07.2023. of the Rector of Sofia University.

Topic of the dissertation: **“Design of Composite Pulse Sequences for Quantum Technologies”**

Author of the dissertation: Hayk L. Gevorgyan

**Candidate details**

Hayk. L. Gevorgyan received his BSc degree (2016) and MSc degree (2018) from Yerevan University, Armenia. Also in 2018, he received an international master's degree at the University of Dijon, France. Hayk. L. Gevorgyan has the best student award of the Republic of Armenia in 2015 and 2017. Also he has won the Marie Sklodowska-Curie scholarship for the period 2018-2021 Hayk. L. Gevorgyan becomes a doctoral student in the group of Academician Nikolay Vitanov in the period 2018-2021.

**General characteristics of the candidate’s scientific achievements**

Composite pulses are a powerful quantum control technique with major applications in various areas of quantum technology. They were originally developed for nuclear magnetic resonance purposes in the 1980s, but have since found wide application in quantum information processing. Composite pulses are a series of pulses with a well-defined relative phase between them. An important example is the broadband composite pi-pulse, which provides a transition probability of 1 over a wide range of values of the pulse area. Another example is narrowband composite pulses that narrow the excitation profile.

Hayk L. Gevorgyan's dissertation is devoted to the development of composite pulses to realize ultra-high precision quantum gates. In the dissertation, new broadband polarization quarter-wave plates are developed, with the potential to be used in broadband optical isolators.

**Chapter one** is an introductory chapter where general concepts of coherent control of quantum systems are discussed. Quantum control of systems includes composite adiabatic transitions and a shortcut to adiabaticity. Quantum control aims to explore a suitable sequence of pulses that minimize the interaction time and make the quantum system stable against experimental inaccuracies. The first chapter discusses various quantum gates such as spin gate, Hadamard gate, phase gate, etc. In the most general case of a two-level system, the unitary evolution operator can be expressed in terms of the Cayley-Klein parameters. For resonant interaction, both parameters depend on the pulse area and the phase of the laser field. Experimental error in the pulse area leads to a loss of precision in the implementation of quantum gates. In the case of a resonant pulse, the precision loss depends linearly on the error. This is where the key role of composite impellers comes in. A series of laser pulses with a strictly defined area and phase difference can increase the robustness of the quantum gate to fluctuations of experimental parameters such as laser intensity and frequency difference.

**The second chapter** of the dissertation is devoted to composite rotation gates. A technique for ultra-precise implementation of a single-particle spin gate using composite pulses is proposed, which allows pulse area error compensation up to eighth order. A key result is finding a shorter pulse sequence that reduces the interaction time. The relative phases of a symmetric and antisymmetric composite pulse train are found to compensate for the first-, second-, and higher-order error. Composite pulses have also been proposed to create an ultra-precise Hadamard gate and an arbitrary rotation gate.

**The third chapter** of the dissertation is devoted to composite phase gates. Quantum phase gates are a key element in any quantum circuit. Composite pulses of four, six, and eight pulses are proposed that compensate for the experimental error from first to third order. The composite phases for higher order compensation are numerically derived.

**The fourth chapter** examines new classes of narrowband and passband composite pulses for constant rotation. Such a sequence of pulses produces narrowband and high-pass rotation single-qubit gates, such as X, Hadamard, and arbitrary rotation gates.

**Chapter five** deals with the construction of composite pulse sequences capable of generating a small transition probability that is robust to variations in experimental parameters. There are applications where a minimum transition probability is required. An example of this is a protocol for generating a single photon in an ensemble of ultracold atoms, creating entangled Dicke states, and achieving ultra-high gate precision. Composite pulses are the only quantum control technique capable of generating a small transition probability robust to variations in experimental parameters. Specific symmetric and asymmetric composite sequences of 2, 3, and 4 pulses are proposed and analytical expressions for the composite parameters are derived. Finally, sequences with more pulses, which reduce the error to a higher order, are considered.

**Chapter six** discusses a quantum-classical analogy for finding sequences of half-wave plates to convert the polarization state from horizontal to vertical or from left to right in an ultrabroadband and ultranarrowband manner. An ultra-wideband polarization rotator is theoretically designed.

**Chapter seven** proposes a method for constructing broadband non-reciprocal polarization quarter-wave plates.

**The eighth chapter** presents general conclusions and perspectives for future development.

**Publications and significance of results**

The dissertation is based on 6 scientific publications, two of which have been published and another two have been accepted for publication. In an article, the dissertation is the sole author.

The nature of the initial works and their number fully satisfy the requirements of the Faculty of Physics of SU "St. Kliment Ohridski" for obtaining the scientific degree "doctor".

**Critical remarks**

The dissertation is written in very good English and the presentation of the results is clear. Before each chapter there is a short introduction and finally conclusions. Basically, I have no critical remarks about the thesis.

I have the following questions for the dissertation student related to the dissertation:

1. Can a sequence of composite pulses be developed in the case where the experimental error is not systematic for each pulse?

2. Can a sequence of composite pulses be used to suppress dephasing processes?

3. Are composite techniques developed for two-qubit gates?

**Personal impressions of the candidate**

I know Hayk personally. L. Gevorgyan. My personal impressions are of a motivated young scientist who grew up in the group of Prof. Nikolay Vitanov.

**Conclusion**

After having familiarized myself with the presented dissertation work, Abstract and the other materials, **I confirm** that the scientific achievements meet the requirements of ЗРАСРБ and the Regulations for its application and the relevant Regulations of SU "St. Kliment Ohridski" for acquiring the educational and scientific degree "doctor". In particular, Hayk L. Gevorgyan satisfies the minimum national requirements in the professional area and no plagiarism has been found in the dissertation and the Author's abstract submitted for the competition.

**GENERAL CONCLUSION**

Based on the above, **I recommend** the scientific jury to award the educational and scientific degree “**doctor”** in professional direction 4.1 Physical Sciences; Physics of Atoms and Molecules.

19.09.2023

Sofia

Peter Ivanov

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