APPLICATION OF QUANTUM TECHNOLOGIES FOR THE DEVELOPMENT OF AN INTELLIGENT CONTROL SYSTEM TO SETUP CURRENTS OF THE CORRECTIVE MAGNETS FOR THE BOOSTER SYNCHROTRON OF THE NICA FACILITY

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This paper is devoted to the study of intelligent control systems, based on computational intelligent technologies and quantum algorithms. The analysis of the application of computational intelligent technologies for development of a robust control system for corrective magnets of the NICA Booster synchrotron is presented.

Keywords: intelligent control systems (ICS), quantum algorithms

1. Introduction

Control systems developed at the beginning of the 21st century that were based on neural networks and PID controllers fundamentally do not take into account the probability of contingency control situations arising and do not include them in the control loop. Such systems cannot guarantee the control goals achievement, such as deterministic setup time, low power loss and high operational reliability. For example, deep multilayer neural networks are hard to train, it needs a lot of time and pure datasets [1].

Currently, one of the promising directions in the development of robust control systems for complex physical facilities is the application of quantum computing to build intelligent controllers based on neural networks and genetic algorithms. The development of intelligent systems with the use of quantum algorithms [2] allows developing reliable physical models that are not sensitive to changes in external conditions and internal changes in system parameters. The use of quantum technologies allows quickly updating and adapting the «knowledge base» for each new situation of management in real time.

The practical significance of the proposed intelligent control system is determined by the prospects of using it for managing objects, the exact mathematical model of which is unknown, which have to operate in unpredictable situations. The development of such a system will improve the efficiency of the NICA complex, speed up the process of setting up accelerators' settings like betatron tunes (Q_x,Q_y) [3], currents of the corrective magnets, etc.

For example, the expansion of the Booster yoke (Figure 1) under the influence of temperature was confirmed. Almost all the distances between the yoke reference holes increased by an average of 100 microns (at distance 4 m) with an increase in temperature (air) by 2-3 degrees, which corresponds to the coefficient of linear expansion of steel. There are 32 corrective magnets placed on the Booster ring, but their geometry and position also depends on temperature in an unknown way. The development of an aided expert control system for these magnets tuning is suggested with the help of computational intelligent technologies, such as evolutionary methods [4], genetic and quantum algorithms [5].

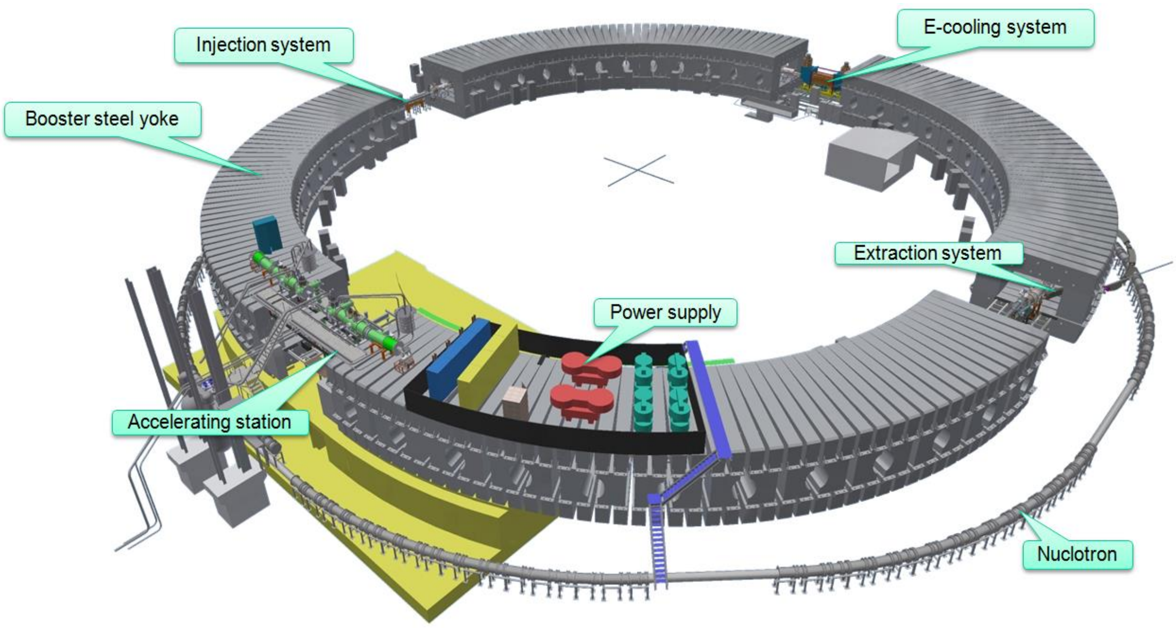

Figure 1. Booster steel yoke of 250 m length (3D model)

2. Quantum technologies

Quantum computing (QC) is a quickly growing field of research thanks to recent hardware advances. The quantum mechanical properties of quantum computers allow them to solve certain families of problems faster than classical computers and build custom robust quantum optimizers [6], which can succeed in machine learning and genetic algorithms (GA). For example, a quantum Grover's algorithm finds an element in an unordered set faster than any classical search algorithm. So we can thus benefit from quantum computers in optimization problems, machine learning and sampling of large data sets. All these tools and technologies can be used for the development of an auxiliary expert control system which can help Booster operators tuning ion beam orbit via corrective magnets' currents.

Today, there are real prototypes of quantum computers available for use in the research [7]. All of them are dedicated to an abstract quantum algorithms investigation rather than to practical usage. Quantum algorithms can be represented as a combination of quantum gates which affects the state of quantum registers. So to work with real data it needs to convert a real numbers into a special quantum gates combination, which is called quantum «Oracle» [8]. For instance, for the implementation of the Grover algorithm adapted for searching a real unordered classical array it needs to construct some kind of quantumly accessible classical memory [9], which is still under development. However there is a libquantum which is a C library for the simulation of quantum computing on a classical computer [10] and it is suitable for developing a new generation of intelligent control systems, based on genetic algorithms (GA).

3. Control system based on genetic algorithms

The process of Booster corrective magnets tuning is multi-input multi-output one (MIMO). Input signals (just simply inputs) are given by ion beam position monitors (Libera Hadron BPMs [11]) installed around the Booster ring and betatron tune measurement system, which both gives an actual beam trajectory and actual working point (Q_x,Q_y) on a Booster resonance diagram.

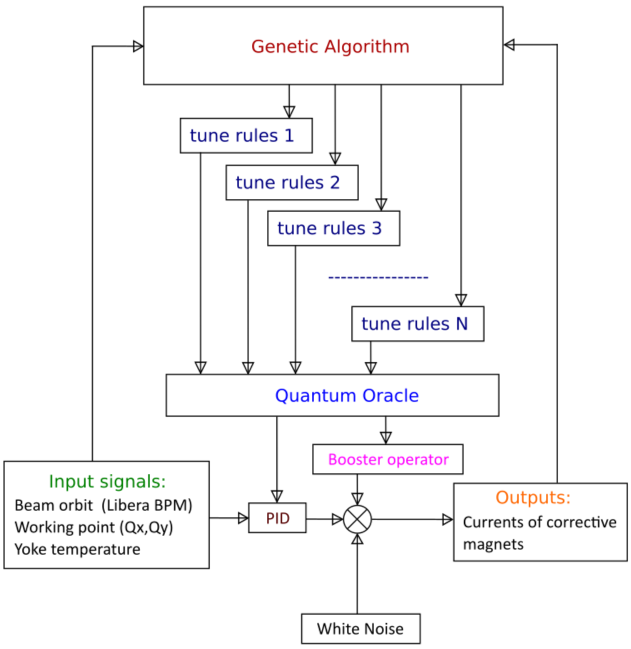

Figure 2. The Booster AICS simplified architecture

Output signals are currents of the 32 corrective magnets. The experience of tuning the orbit of the ion beam of the Nuclotron supposes that it will take a lot of time to tune the currents of the correction magnets of Booster. So to speed up the tuning procedure of beam orbit, an auxiliary intelligent control system (AICS) based on GA is proposed to develop [12], which will give to a Booster operator hints how to change corrective currents. The architecture of AICS for Booster is shown in Figure 2.

4. Conclusion

Compared to other control systems architectures, which are based on tuning algorithms produced by some foreseen rules and limitations, an auxiliary intelligent control system, based on genetic algorithms and quantum technologies offers more flexibility by providing selection of best matching tune rules according to unforeseen changes of environment.

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