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UPGRADE OF THE AGOR CYCLOTRON CONTROL SYSTEM AT UMCG-PARTREC

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Abstract

The transfer of the AGOR cyclotron to the University Medical Center Groningen (UMCG) initiated investments for long-term reliability. Recent, current and upcoming upgrades and additions include replacing the Operational Technology (OT) network, control system software, PLCs and the RF resonator control. Several in-house developed electronic devices are also undergoing updates. Simultaneously, a new beamline is under construction. However, these investments also come with challenges such as keeping the cyclotron operational throughout the upgrade process, managing limited manpower, and mitigating supply chain disruptions exacerbated by COVID-19. Despite these hurdles, UMCG-PARTREC is committed to proactive investment in the cyclotron's future, securing its reliability for ongoing scientific research.

INTRODUCTION

The superconducting AGOR cyclotron (see Fig. 1) began development in the late 1980s and was commissioned in 1997. In 2020, when the institute KVI was transferred from the University of Groningen (RUG) to the University Medical Center Groningen (UMCG) and became PARTREC [1], it marked the beginning of an upgrade process aimed at ensuring reliable operation for the foreseeable future. Through proactive investments, we are modernizing components that may be up to 30 years old to meet current standards, with the goal of averting potential reliability issues in the future. In this paper, we will describe some of the upgrades and challenges faced at PARTREC.

Figure 1: The AGOR cyclotron.

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UPGRADES

The facility's recent, current, and forthcoming upgrades and additions encompass the following:

Operational Technology (OT) Network

The current OT network is made up of controllers and I/O modules based on the Bitbus fieldbus, linked via Bitbus servers. Bitbus is considered to be a technology soon to be phased out, hence a pilot study was conducted to evaluate the feasibility of using a National Instruments CompactRIO (NI-cRIO) based subrack in place of Bitbus-based controllers for analog and digital I/O (see Fig. 2). Additionally, a similar PLC-based solution is currently under investigation. Both of these alternatives are able to accommodate our in-house developed Digital InterFace card (DIF) and InterFace for Analog card (IFA). The DIF cards provide current buffering and isolation and the IFA card provides analog output voltage drop compensation due to long cabling. They have the same type of connector receptacle as the equivalent Bitbus cards which enables the reuse of cables for existing equipment when desired, making it a drop-in replacement for our Bitbus based I/O cards.

Figure 2: A photograph of a pilot subrack for the replacement of Bitbus based controllers using an NI-cRIO controller and custom-made DIF and IFA cards.

For compatibility reasons, both pilot projects employ an Ethernet interface with Modbus TCP to connect to the servers hosting the control system software. Nevertheless, if we opt to update our control system software as described in the subsequent subsection, we are likely to transition to the OPC UA communication protocol. This shift is motivated by the observation that OPC UA appears to offer advantages in data throughput when compared to Modbus TCP.

Control System Software

Our current control system software, Vsystem by Vista Control Systems, Inc. [2], though still manufacturer-supported, suffers from persistent instability issues,

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necessitating frequent reboots that disrupt cyclotron operations. Additionally, a review of previous ICALEPCS proceedings highlights Vsystem's limited adoption within the control system community[1], raising concerns about its future support.

Consequently, we are exploring the adoption of new control system software, with the primary aim of enhancing reliability for both short-term and long-term operations.

Among the alternatives under investigation is EPICS, despite its acknowledged high manpower requirements. Simultaneously, we are assessing commercially available options. Notably, one such alternative is provided by a manufacturer that offers both control system software and compatible PLCs. While our recently upgraded PLCs would remain unaffected, this new brand presents an opportunity to simultaneously replace the control system software as well as the Bitbus-based OT network using their PLCs. The seamless integration of this control system software with its manufacturer's PLCs holds the potential to significantly reduce the time required for integration of the OT based I/O into a newly developed control system software.

PLCs

Our PLCs are decentralized controllers which are primarily used for the control of industrial devices such as vacuum pumps, valves, and compressors. PLC code mainly consisted of Function Block Diagrams (FBD), sometimes in combination with parts of Sequential Function Charts (SFC) and Structured Text (ST). We are currently upgrading to a newer generation of PLCs (see Fig. 3) and for every PLC upgrade we rewrite the old code to ST only.

Figure 3: A photograph of an upgraded PLC.

Note however that for the PLC controlling the helium compressor, the rewrite operation of the original code to ST was considered too high a risk as the helium compressor is a vital part of AGORs cryogenic system and the loss of cooling would create a cascading effect causing a subsequent downtime up to a year. In this case the PLC hardware was replaced, but the original code was maintained. The overall PLC upgrade process is ongoing and is almost complete.

RF Resonator Control

Based on the beam frequency selected by the operator the length adjustable resonators must be set accordingly. When the beam is accelerated in the cyclotron the tuning of the resonators is maintained based on the phase difference between the injected power and the measured current. Currently the RF resonator control is performed by a Bitbus-based controller that controls the motor drives which in turn control the resonator motors. A decision was made to replace the Bitbus controller and subsequent I/O hardware with an NI-cRIO controller and I/O modules.

As for choosing a new motor and motor controller we are investigating a suitable solution that is compatible with our chosen controller. This will likely mean that the motor controller interface will be based on the Controller Area Network (CAN) protocol.

An important obstacle that has to be overcome is the decision on what type of feedback sensor is desirable when considering that it is used in a radiation environment. In the past we have observed that encoders can be susceptible to radiation damage. We therefore intend to initially subject the selected encoder to an extensive radiation test, simulating the expected lifetime dose at the designated locations.

Custom, In-House Electronics Upgrades

Beam Profile Electronics The current beam profile electronics use components that are hard to procure which puts stress on the availability of spares. Also, they have a Bitbus interface to the control system. A new beam profile system is designed as a generic, multichannel I-V converter so that it can be connected to the I/O of any OT network. Prototype tests are ongoing.

Beam Current Readout Like the beam profile electronics, the existing beam current readout modules also use components that are difficult to procure and use a Bitbus-based controller. A new beam current readout PCB was designed as a generic I-V converter that can be linked to the I/O of any OT network. Prototype tests have successfully completed and we are in the process of series production.

RF Analog Regulation System The RF analog regulation system employs feedback loops to regulate the RF power and phase, based on operator settings and feedback values from the resonators (see Fig. 4[2]).

In the old design each blue module in Fig. 4 consisted of a separate cassette (see Fig. 5).

[1] An examination of the ICALEPCS proceedings from 2011 to 2021 highlights that only ISIS Neutron and Muon Source in Didcot, United Kingdom, and Argonne National Laboratory in Lemont, USA have made mentions of utilizing Vsystem by Vista Control Systems, Inc. The former institution outlines their ongoing transition to EPICS [3], while the latter, due to their limited staff capacity, relies on Vista-provided libraries to achieve the necessary functionality [4].

[2] AGOR has three resonators, each equipped with its own RF regulation system, and they collectively share the signal from the reference generator. To enhance clarity, neither of these aspects is represented in Fig. 4.

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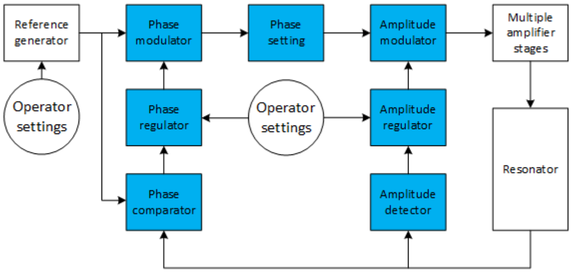

Figure 4: Simplified overview of an RF system for one resonator including its RF analog regulation system (marked blue).

Figure 5: A photograph of the old RF analog regulation systems.

The new design incorporates functional improvements and condenses these seven modules into a single cassette, resulting in fewer expected issues with faulty cables and connectors, and enabling us to maintain a larger stock of spares (see Fig. 6).

Figure 6: Photograph of a prototype of the new RF analog regulation system in which several modules are integrated into one.

Prototype tests and series production have successfully completed and the new units are in the process of installation.

New Beam Line

The UMCG Radiotherapy department, in collaboration with technical staff from UMCG-PARTREC, is in the process of constructing a new beamline for the AGOR cyclotron (see Fig. 7). This project is subject to a strict deadline for the commissioning of control hardware and software. Consequently, it will not be directly involved in the upgrade of the OT network and control system software. Instead, the selection of its OT network and control system software will be tailored to meet the specific requirements of this beamline. Nonetheless, it is anticipated that this new beamline will incorporate the new beam profile electronics and beam current readout electronics mentioned earlier.

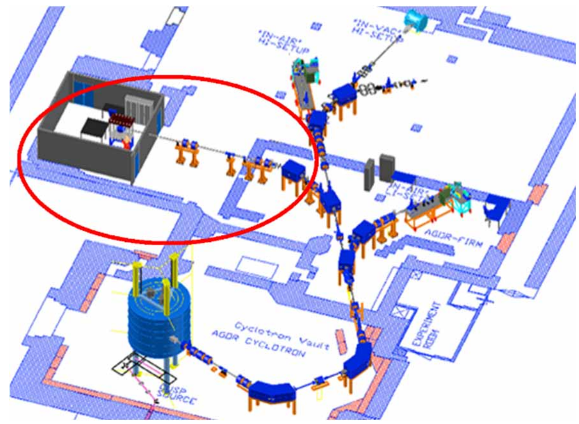

Figure 7: Layout of the PARTREC facility, showing the AGOR cyclotron at the bottom left and the new beam line marked in red.

CHALLENGES

With the upgrade of AGORs control system come operational and practical challenges that must be addressed.

Cyclotron Operation

The cyclotron must remain operational throughout the upgrade process. Although prolonged maintenance and upgrade periods are feasible, they should be limited to a maximum of 1-2 months. For the installation of equipment that serves as an upgrade of existing equipment this usually is enough. However, sometimes such equipment does not work as planned, thereby requiring a roll back to the old situation. This requires extra time in the planned shutdown period because rolling back to the old situation takes time as well.

Manpower

While the technical staff is engaged and hardworking, they can only dedicate a limited amount of time to both operational duties and upgrades. Outsourcing can alleviate the workload, but its usefulness is constrained by the need for input and support from the technical staff. Also, the type of work that can be outsourced is in practice limited as there are various tasks and projects that require a lot of manhours to get acquainted with the relevant details and boundary conditions, leading to significant development costs in the case of outsourcing.

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Lead Times

Although the COVID-19 induced lead times are not as bad as during the height of the pandemic, we are still faced with long lead times that require careful planning. The strong increase in lead times of electrical components has also been the main reason for numerous redesigns during active projects. The main reason for this is that even though at the time of designing a PCB a component might be readily available, by the time the prototype is evaluated and series production can start, that component might have a lead time of up to 2 years. To circumvent this problem, we see no alternatives but to purchase the required amount of critical components as soon as the component is used in the design. This ensures that we have enough components for series production should the prototype tests be completed successfully.

CONCLUSION

The upgrade of the AGOR cyclotron control system at UMCG-PARTREC represents a significant step in ensuring the long-term reliability and functionality of the facility. These current and upcoming upgrades encompass several critical areas, including the replacement of the Operational Technology (OT) network, control system software, PLCs, RF resonator control, and custom in-house electronics. Additionally, the construction of a new beamline is underway, further expanding the facility's capabilities.

While these investments are vital for the future of the AGOR cyclotron, they are not without challenges. Maintaining operational continuity during the upgrade process is a priority, with limited allowable downtime. The availability of manpower and the balance between operational duties and upgrade projects present ongoing considerations. Moreover, dealing with lead time issues, particularly in the context of COVID-19 disruptions, requires meticulous planning and the procurement of critical components well in advance.

The ongoing efforts and investments in the AGOR cyclotron control system underscore the commitment of UMCG-PARTREC to ensuring its sustained operation and reliability for ongoing scientific research.

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