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OPERATIONAL EXPERIENCE IN THE TREATMENT OF OCULAR MELANOMAS WITH A NEW DIGITAL LOW-LEVEL RF CONTROL SYSTEM

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Abstract

Ocular melanomas have been treated for the last 20 years at the Helmholtz-Zentrum Berlin in collaboration with the Charité – Universitätsmedizin Berlin. However, parts of the initial control system electronics date back to the 1970s, when the machine was installed. Facing a critical shortage of legacy and obsolete components and with the down-time due to failures in the electronics on the increase, a decision was made to install the digital low-level RF control system, developed by iThemba LABS, on our k=132 cyclotron. A short description of the installation and commissioning process, which occurred in April 2017, and the experiences of the first two years of operation with the new digital low-level RF control system is presented.

INTRODUCTION

The HZB cyclotron with its two 30 kW RF amplifiers was built 45 years ago [1]. Over time some components of the whole cyclotron have been renewed, rebuilt or optimized. Especially in the high frequency systems, the 1 kW tube driver amplifiers were replaced by 2 kW semiconductor amplifiers, the system frequency generator was replaced by a network compatible device and various analogue displays were replaced by digital displays.

However, many components in both the low level and high level system of the RF are still from the early days. The two RF amplifiers in the high level system are still in their original condition, with the exception of minor optimizations, and are very robust. Spare parts for the amplifiers are available or can be made by ourselves. Some main components like e.g. the 100 kW amplifier tubes are still manufactured. Failures in the high level systems occur mainly due to leaks and defects in the water cooling system, and can be fixed by replacing or repairing the unit. The electronic modules in the low level systems were constructed using the wire wrap technology common at the time (Fig. 1), which is relatively compact despite the large number of components, but makes repair and maintenance more difficult. With the increasing age of the electronic modules, contact problems and wire breaks on the wire wrap cards occurred in addition to defective components.

Since various built-in special high frequency components and high-level logic ICs are no longer available, repairs were made even more difficult by increasingly scarce spare parts. Due to these problems and the desire for a better overview and diagnosis of the RF parameters, it was decided to replace the complete low level control of the two RF systems. An in-house development was rejected due to lack of personnel and time, and adaptable ready-made solutions were sought.

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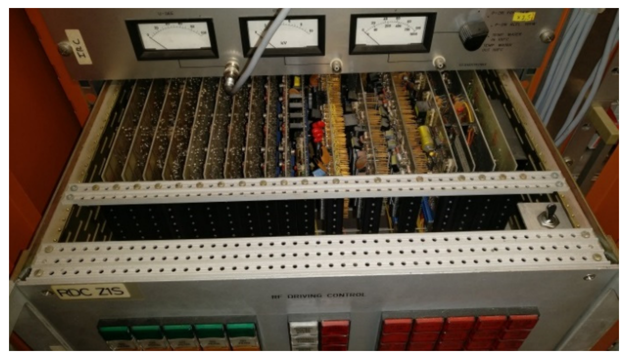

Figure 1: Old low level RF control system.

The digital low level RF (LLRF) control system newly developed and built by W. Duckitt at iThemba LABS [2] in Cape Town South Africa seemed to be suitable to replace the low level electronics of the RF systems at the HZB cyclotron. At this time in 2015, the digital LLRF control system was already successfully used with both injector cyclotrons SPC1 and SPC2 at iThemba LABS and the installation at the main cyclotron SSC and various buncher systems were planned. In October 2015, after clarification of the adaptability of the system and the technical implementation at the HZB cyclotron, it was decided to use the LLRF control system from iThemba LABS on both our RF systems.

PREPARATIONS AND INSTALLATION

From the beginning of 2016 to May 2017, all preparations, conversions and necessary measurements and tests were carried out in addition to normal accelerator operation during the maintenance periods. iThemba LABS built five LLRF control system modules for the HZB cyclotron and delivered them in March 2017. Two of the modules are planned for the north and south system at the cyclotron, one module serves as reference oscillator and two modules are intended as reserve or in the future for the buncher at the accelerator. For a synchronized operation of the modules, a distribution of the reference frequency and a 10 MHz clock signal had to be prepared using existing RF splitters. Since the installation of the LLRF control system had to take place without disturbing the accel-

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erator operation, no modules of the old RF control system could be removed to create space for the new system. In order to allow the installation of the new modules, some of the old RF control modules were moved or rebuilt. The three LLRF control system modules with 6 rack units each were installed and connected to the reference and clock signal distribution. For the hardware connection of all actuators, read-outs, interlocks, analogue and digital signals of the RF systems to the control software, four 4-rack large modules units were built. In these modules, the signals are read or output via Beckhoff EtherCAT terminals and made available to the control software as parameters. For this purpose, two modules for motion control and one module each for the analogue and digital signals were set up (Fig. 2).

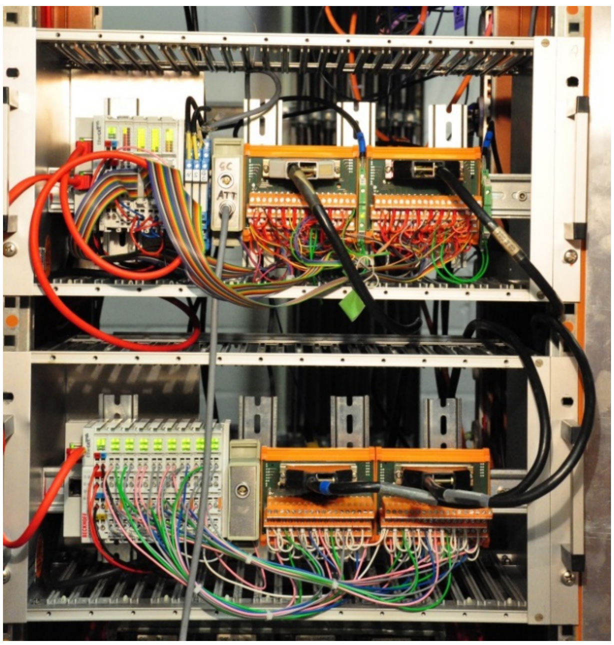

Figure 2: Modules with Beckhoff EtherCAT terminals for analogue and digital signals.

In addition, two server PCs with Linux operating systems were set up and installed, which represent the central interface between the LLRF, the Beckhoff EtherCAT terminals and the client PCs in the control and electronics room. The two Motion Control modules were then tested in interaction with all motors and position read-outs in the resonance tuning and control of the RF systems, and the respective limit parameters were determined. In order to ensure a fast connection of the analogue, RF, control and interlock signals of the new RF system and a fast change between the old and the new RF control, all signals of both RF systems were connected on patch panels (Fig. 3).

Subsequently, all analogue and RF signals were measured at the patch panels under different operating conditions of the cyclotron RF.

Amplifiers and attenuators were prepared to adjust the level differences between the measured and the required signal levels of the LLRF. The necessary software adaptation of the LLRF to the resonance control system at the HZB cyclotron, which differs from the iThemba LABS cyclotrons, was performed by iThemba LABS.

Figure 3: Patch panel for RF signals.

COMMISSIONING

The commissioning of the LLRF at the HZB cyclotron took place at the beginning of May 2017 [3], for which W. Duckitt and J. Abraham from iThemba LABS were on site. Since small changes and adaptations to both the software and the hardware are still necessary during the piecewise commissioning of the LLRF, two weeks were planned for the entire process.

Changes in the software mainly included adjustments of the gain and attenuation factors as well as phase and delay values in the resonance control. In addition, the limit values of all motion control actuators in the software were adjusted. On the hardware side, additionally required floating contacts were created and some interlocks were linked, and level adjustments were made with the prepared amplifiers and attenuators. In the first step, the EPICS based user interface was set up on the client PCs and the two server PCs were configured. The RF systems were tuned with the old RF control to the standard therapy frequency of 19.3187 MHz to obtain a starting value of the resonance tuning for the LLRF. Then the RF was switched off again and all signals at the patch panels were plugged into the new LLRF modules. In the next step, the north RF system was first started with the LLRF and, after optimizing the amplitude, phase and resonance control, stable operation under therapy conditions with 115 kV amplitude was achieved.

Subsequently, the same procedure was successfully performed for the south RF system, and both RF systems could be operated with the new LLRF after only two days (Fig. 4).

In the next step, resonance tuning to standard operating frequencies in the range of 10-20 MHz and further optimizations in the control loops in the LLRF were performed for both systems.

Finally, the interlock to block the operator interface, which is important for therapy when treating patients, was integrated.

In total, only one week was needed for commissioning instead of the planned two weeks. After commissioning, stability tests and several changes between the old and the new RF control were carried out in the second week. Comparative measurements of the therapy beam with the

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new and old RF control showed identical results at the target site.

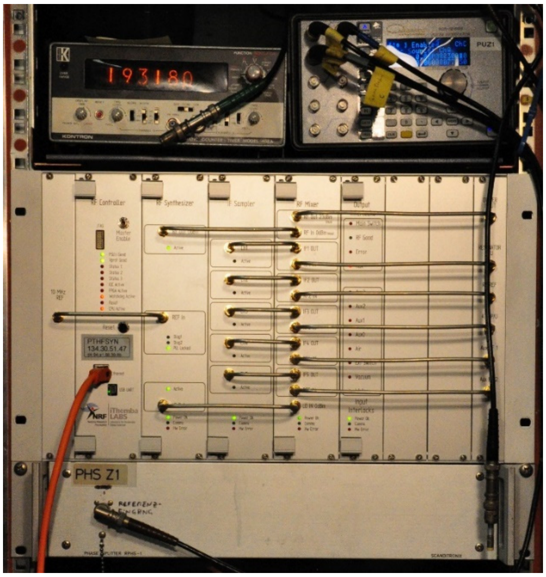

Figure 4: One of the LLRF modules installed at HZB.

TWO YEARS OF OPERATION

The therapy block in May 2017 was still carried out with the old RF control, as some adjustments still had to be made in the CAMAC control system for the new LLRF. The first therapy performed with the new LLRF followed in June 2017. Already during the adjustment of the accelerator the starting of the RF systems by the automatic resonance search of the LLRF was easier and faster than the manual resonance search of the old system.

Thus, the cold start of the RF systems after the maintenance period can be carried out by all operators themselves without any problems and without the help of the RF group. A further simplification for the operators is the visualization of the status as well as the short- and long-term display of the amplitudes and phases of both RF systems on the operator interface in the control room (Fig. 5).

This allows a better assessment of the status of the RF systems during the beam time. Both systems now run more stable, with phase stability improving from 0.1° to 0.02° and amplitude stability from 0.5% to 0.7%. The three bunchers and the pulse suppressor used only for experiment operation were synchronized with the new LLRF via the reference frequency. Thus the bunchers and pulse suppressor could be used identically to the old RF control for beam optimization at the cyclotron. Test measurements with bunched and pulsed 68 MeV proton beams with multi turn and single turn extraction showed a stable interaction of the RF systems.

The failures of the RF systems have been significantly reduced since operation with the new LLRF and are now mainly limited to problems with cooling water lines and power supply defects in the anode and grid voltage.

In the last two years only one problem has occurred: In October 2017, after a change of cyclotron frequency, the LLRF of the south system's phase modulator became sporadically unstable.

Figure 5: Operator interface for the north and south RF.

After consultation with W. Duckitt of iThemba LABS, the problem was identified as a suboptimal tuning of the RF power amplifiers output stage, resulting in the loop instability.

To solve the problem, the integral coefficient of the phase modulator's PID controller was first lowered. This allowed the power amplifier to be optimised at rated power. Thereafter the integral coefficient was returned to its nominal value and normal operation continued.

Downtime for magnet power supplies of the cyclotron, water leaks or RF are all counted in one number. Thus the trend of reduced downtime thanks to the LLRF is not immediately visible in Fig. 6, however, half of the downtime in 2017 was due to problems with water leaks and a power supply of a trim coil magnet.

Since June 2017 both the proton therapy and the experiment operation have been carried out successfully exclusively with the new LLRF.

Besides the standard 68 MeV proton beam (f_{RF} = 19.3187 MHz) a 90 MeV ^{4}He beam (f_{RF} = 17.2576 MHz) has been delivered successfully for experiments.

OUTLOOK

The next step is the conversion of the buncher systems to the LLRF, as problems with the procurement of spare parts are increasingly occurring here as well. This would also provide a better overview of the condition of the buncher and an easier optimization of the phase relationships of the RF systems.

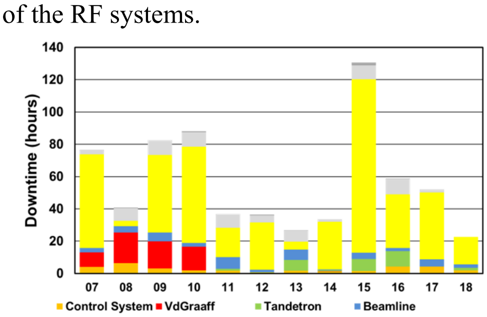

Figure 6: Downtime of the accelerator over the years. Since the installation of the new LLRF the downtime due to the cyclotron has been reduced. In 2017, only half of the cyclotron downtime was due to problems with the RF.

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CONCLUSION

The preparations and installation went without any major problems and could be carried out during the maintenance periods or parallel to operation. Commissioning was faster than planned, with the installed patch panels and previous testing of the motion control modules proving essential. The RF systems are now more stable and provide a better overview of their condition. Support from iThemba LABS for LLRF replacement modules as well as for problems or changes to the EPICS software is essential. More than 400 patients have been treated since the commissioning with the new LLRF.

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