HIGH POWER RF SUPPLIES FOR THE FAIR INJECTOR LINACS

W. Vinzenz, G. Schreiber, L. Groening, W. Barth, M. Hoerr, H.-L. Dambowy
GSI, Darmstadt, Germany

Abstract

The operating frequency of the FAIR proton linac was fixed to 325.224 MHz two years ago. Even though the six coupled CH-structures need slightly different RF levels, the proton linac will be equipped with identical RF power sources. That applies also for the RFQ structure.

To supply the FAIR accelerators with a good beam quality by the UNILAC as the high current heavy ion injector for FAIR as well as a high duty factor accelerator for nuclear physics experiments, different upgrades and modifications have to be made at the RF components.

The provision of an excellent RF operation for the next years postulates some general renewals. This paper describes the actual status of the proton linac RF system and the future requirements for the existing UNILAC RF systems.

INTRODUCTION

In the context of the dedicated proton linac within the FAIR project seven high power RF amplifiers up to 2.5 MW at 325 MHz have to be installed. The Toshiba E3740A klystrons selected meanwhile can provide enough power for the overall RF pulse length of 200 µs at a repetition rate of 4 Hz with sufficient margin.

For the UNILAC altogether eight high power RF tube amplifiers at 36 MHz (3 up to 2 MW) and at 108 MHz (5 up to 1.6 MW) will be involved in the future beam operation for high current beams (up to 800 kW beam load in addition at HSI) and a so-called long pulse mode (up to 50% beam duty cycle for a/q ~ 6). The FAIR requirements will meet or exceed the present capabilities in maximum power and duty factor. This leads to detailed improvements of the existing amplifiers and power supplies involved.

FAIR PROTON LINAC

Choosing an operating frequency of 325,224 MHz was triggered by an existing prototype of a coupled CCH-Structure [1] and the presence of high power klystrons used at the J-PARC facility. Following these facts, the number of RF power sources for the DTL could be reduced to six. Even though the RFQ needs less than half the RF power with respect to one CH-structure we decided to stay at the same amplifier type. This makes sense due to spare part storage and reduces the diversity of amplifier types. Two more identical amplifiers will supply the bunching cavities at the same frequency with an expected RF power of 15 and 50 kW, respectively.

Test Bench

For tests with all infrastructure components of one klystron section a test bench is mandatory. Also the first CCH-Structure has to be tested in an X-ray shielded cave. In February 2008 the first Toshiba klystron was successfully tested at manufacturer's site in Japan and delivered to GSI in April. A 100 W driver amplifier was ordered and delivered by RES Ingenium (Italy) in 2007. At present a test bench [Fig. 1] is under construction, offers for additional technical equipment are available. All power supplies will be developed by the GSI power supply group. Because of the very low duty factor a crowbar-less solution has been developed [2]. The prototyping of the LLRF is made by GSI, based on a system that will be installed at the GSI/FAIR synchrotrons using IQ detection and digital control FPGA/DAC solutions. After some technical revision the measurement and data acquisition system used at the High Current Injector (HSI) RF section will be also implemented at the proton linac.

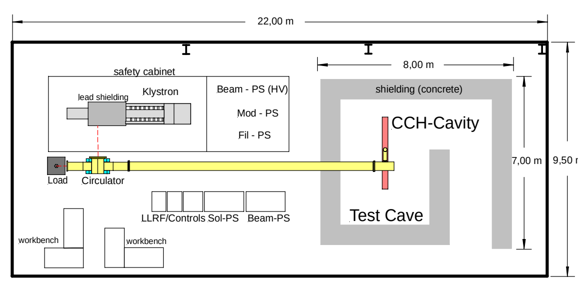

Figure 1: Layout of the test bench.

Some special features on behalf of pulse forming and tube protection purposes will be updated from the UNILAC LLRF system and functionally included in the new digital control system. There are established and approved methods for pulsed RF operation at high power levels reducing faults and off-times as well as enormous time savings during cavity conditioning. Due to the higher demands for the proton linac, the existing analogue value measurement was meanwhile improved. The standard LLRF layout is shown in [Fig. 3]; an overview of the special functions is shown in [Fig. 6].

Proton LINAC RF System

The layout of a klystron driven high power RF system has been sufficiently described in conference proceedings. Building restrictions e.g. the maximum length of the klystron gallery as well as the cost optimised infrastructure of the building has to be taken into account, however. As [Fig. 3] shows seven klystrons will be installed inside the RF-Gallery at ground level. Each klystron is feeding one cavity, which makes the variation of the linac output energy very simple. Further more all electronic devices and supply units are arranged in the meaning of this solution. The RF power transportation is made by waveguides (WR2300), for klystron protection an isolator is installed at each output. The calculated progression of the output power is shown in [Fig. 2]. At a repetition rate of 4 Hz the RF ON time will be maximum 200 µs whereas the BEAM ON time is 40 µs. The remaining time is for cavity filling and safety margin.

Two identical amplifiers will supply the rebunching cavities, one in-between the RFQ and the first CCH-structure, the 2nd one at the end of the proton linac. These amplifiers will be placed at the 2nd floor of the LINAC building. The decision whether to use either tube (e.g. TH 571) or solid-state amplifiers has to be made as soon as possible.

Considering that the proton linac is part of the FAIR project, which includes more than forty high power RF systems, some 'generic specifications' have been fixed [3]. These standards widely affect the power supplies, PLC soft- and hardware, LLRF systems, and the interface to the main control system.

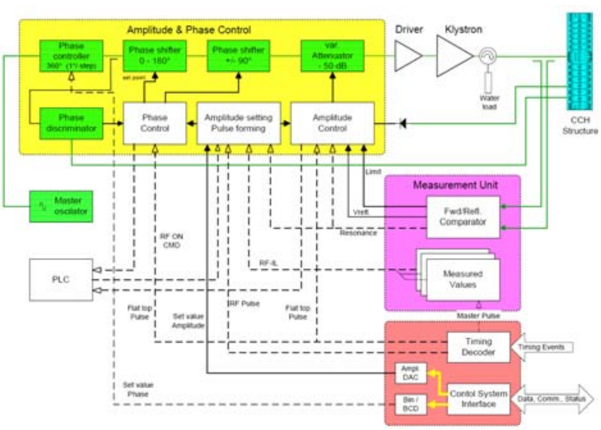

Figure 2: LLRF System

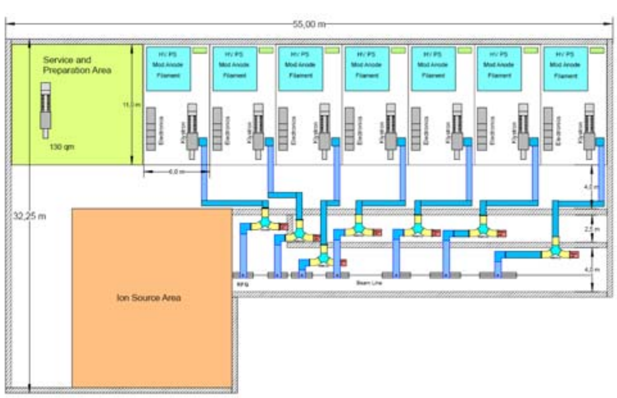

Figure 3: Layout klystron gallery.

NEW UNILAC RF REQUIREMENTS

The future requirements for the FAIR operation are directly affecting each of the three existing GSI injectors in different manners:

High Current Injector [HSI]

- Higher beam load up to 18 mA
- Additional copper losses at the RFQ

High Charge Injector [HLI]

- Increased duty factor (50%) at 120 kW RF Pulse power
- 60 kW CW for future operation

Post Stripper Section [Alvarez]

- Additional beam load up to 15 mA at the high beam current mode
- Increased beam duty factor (50%) for a mass to charge ratio of 6

To ensure a safe and stable operation of all the involved accelerating and bunching structures for the next three decades a bundle of additional upgrade steps has to be planned, calculated and realized:

Modification of the involved power supplies

- PLC implementation
- Enlarging of the capacitor battery

Upgrade of all LLRF equipment at 108 MHz

- Modification of the bandwidth
- Renewal of measurement equipment
- Improvement of the pulse rise time

Amplifier replacement at 108 MHz (partly)

- Exchange of the pre amplifier chain within the 200 kW amplifiers towards 8 kW solid-state-amplifiers

UNILAC RF UPGRADE

High Current Injector [HSI] 36 MHz

After electrode replacement at the RFQ of the High Current Injector (HSI) higher beam transmission will increase the beam current about 20 %. That leads to beam loads of 180 kW at the RFQ and 800 kW at IH1 and IH2 each. Additional copper losses at approximately 300 kW at the RFQ have to be fed. Based on the fact that the three 2 MW_{peak} final stages at this accelerator section are DC supplied by one common power source, the storage capacitor has to be enlarged by 135 µF (currently 880 µF) to stay below 4 % voltage drop during a 3 ms RF pulse. Therefore the DC power supply will be extended with two capacitor cabinets. The design of the electrical and mechanical reconstruction is on the way and the capacitors are at hand. Work can be started by beginning of the planned shut down for the electrode replacement in February 2009 and has to be finished before commissioning of the RFQ tank in May 2009.

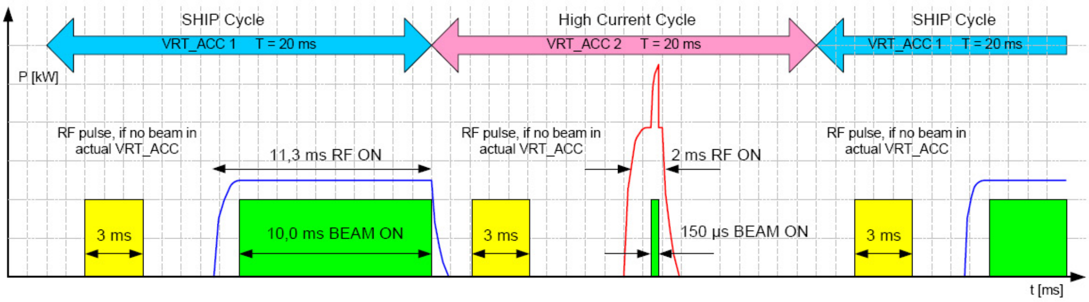

Figure 4: Example of the planned pulse train at the UNILAC.

High Charge Injector [HLI] 108 MHz

A completely new RFQ, designed by A. Schempp (IAP Frankfurt), will be installed in September 2009. The cavity needs 120 kW RF pulse at 50 % duty factor corresponding to 60 kW CW. The performance of the amplifiers (equipped with RS1084CJ) has been tested on dummy load in 2007.

Post Stripper Section [Alvarez] 108 MHz

The UNILAC RF amplifiers supplying Alvarez 1 and Alvarez 2 have to provide additional beam load by approximately 400 kW at 150 µs pulse length at 5 Hz repetition rate, alternating with a RF power level of roughly 600 kW at 57 % RF duty factor and 50 Hz repetition rate. This mode will push the amplifiers to the limits of the tube operation possibilities. During the UNILAC design more than thirty-five years ago, both operating modes have not been taken into account (standard operation 5ms at 50 Hz). The connected power supplies have to be upgraded for the long-pulse mode. Performance measurements have shown that the final stage at Alvarez 1, running the RS2074HF, is able to provide the requested long pulse power only up to 45 % RF duty factor in maximum after optimised tuning. To reach the required gap voltage the amplifier has to deliver approximately 700 kW output power. This means more than 350 kW CW, whereas the average anode dissipation is 320 kW. Under best conditions the maximum output of the RS2074HF is about 1,6 MW pulse power at 108 MHz with a repetition rate of 20 ms and a pulse length of 4 ms.

It has to be pointed out that a safe and stable operation has to be ensured. In consideration of the above-mentioned operating conditions, it is obvious that the existing equipment is not qualified to work in a pulse-to-pulse operation with alternating requirements shown in [Fig. 4].

To reach the expected requirements means a jump to the next power level in RF tubes, which can be a Thales TH526B, Eimac 8973, or equivalent. In case of changing the tube type a new design of the final stages for at least one of the Alvarez stages is required. The remaining final stages at Alvarez 2a, 2b, 3 and 4 have to be upgraded in that way that there is a full inspection of the RF circuits. The complete LLRF equipment has to be improved in the sense of extending the over-all-bandwidth, timing aspects and measurement.

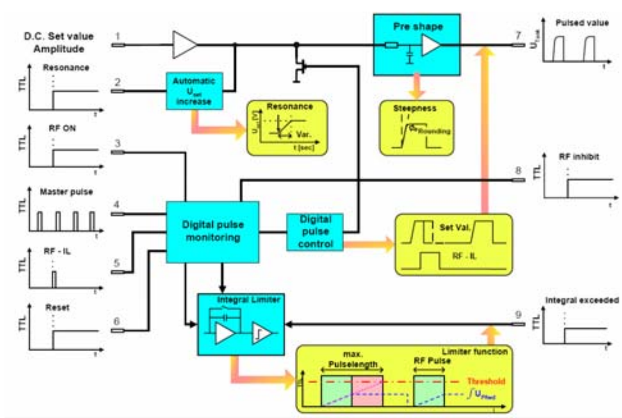

Figure 5: Pulse forming and operating automation.

Single-Gap-Cavities

Due to the age of the 200 kW driver amplifiers of 35 years for the Alvarez structures, and the identical amplifiers for the single-gap cavities and some bunchers, problems arose on the procurement of spare parts. Special components for the input circuits of the RS2024CW tube-pre-driver–stage and electronic components for the R&S solid-state amplifiers are no longer available. A study, established in 2007, follows the idea to replace these 50 W, 300 W and 10 kW (tube) amplifiers in a row against one 8 kW solid-state amplifier. A very helpful design and construction idea came from RES Ingenium (Italy). If this study ends successfully, we will have to upgrade about 25 amplifiers in that way. This means removal of the wiring, mechanical realignment, as well as the new installation of LLRF, PLC and control equipment.

REFERENCES

[1] G. Clemente “The Room Temperature CH-DTL and its application for the FAIR p-Injector" Thesis 2007
[2] H. Ramakers “Common Remarks Power Converters”, GSI Internal Note 2006
[3] Dr. H. Klingbeil et al. “FAIR Standardization RF Systems”, GSI Internal Note 2006