RF SYSTEM DEVELOPMENT FOR THE NEW 108 MHz HEAVY ION HIGH-ENERGY LINAC AT GSI

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Abstract

The GSI heavy ion linac UNILAC is in operation successfully since about 40 years. A replacement of the post stripper section is proposed to provide heavy ion beams for the future FAIR facility. Design studies for a new 108 MHz high-energy (HE) linac optimized to accelerate high brilliance and high current ion beams up to U^{28+} for synchrotron injection are in progress. Thus, the UNILAC will be converted into a short-pulse accelerator, the RF duty cycle being reduced from around 30 % to ≤ 2 %. To feed the future HE linac and to prepare for the FAIR commissioning, a major modernisation of the existing post stripper RF systems is planned from 2015 to 2017. Besides, the development of a new 1.8 MW cavity amplifier prototype was started recently, based on the widely-used THALES tetrode TH 558SC promising an availability for at least 25 years. New 120 –150 kW solid state driver amplifiers will replace the existing tube drivers. A digital LLRF system designed by industry was integrated into an existing amplifier driving a single gap resonator and was tested including ion beam tests. An overview of the RF system design and of the planned upgrades is reported including some results of the d-LLRF tests.

INTRODUCTION

For the upcoming new FAIR facility at GSI [1] all ion beams heavier than protons will be provided by the existing GSI accelerator complex used as injector system, comprising the heavy ion linear accelerator UNILAC [2] and the subsequent synchrotron SIS18.

The UNILAC started operation in 1975 [3]. Whereas the original Wideröe pre-stripper linac was replaced by a high-current injector in 1999, the 108 MHz post stripper linac with five Alvarez tanks followed by ten single-gap resonators as well as the corresponding RF systems are still in operation since the earliest days of the machine. The UNILAC provides ion beams up to uranium for various experiments at the output of the linac at variable energies and high duty cycles as well as high current beams with highest magnetic rigidities for injection into the SIS18. Up to three ion species with different beam currents, magnetic rigidities, and pulse lengths are accelerated in a pulse-to-pulse time-sharing mode with varying requirements for each pulse at 50 Hz pulse repetition rate and RF pulse lengths up to > 6 ms, corresponding to a max. RF duty cycle of > 30 % [4].

The Proposed High Energy Linac

Due to an increasing number of diverse types of failures at the linac cavities and due to operation limitations, a replacement of the post stripper linac by a new high-energy (HE) linac and an extensive modernisation of the RF systems were proposed to assure reliable operation and the beam quality required for FAIR [5][6]. The new HE linac will serve the needs as a FAIR injector linac, with fixed end energy, short RF pulses (≤ 2 ms), and low duty cycle (≤ 2 %, max. 10 Hz RF pulse repetition rate). Demands for ion beams with high duty cycle and variable energies in the MeV/u regime, e.g. for the super-heavy element program, will be met by a proposed independent superconducting cw linac.

Two different HE linac options are currently studied for acceleration of ion beams up to 15 mA U^{28+} from 1.4 MeV/u to 11.4 MeV/u (85 MV total acceleration voltage) [6]: an IH type drift tube linac comprising six cavities or a conventional Alvarez DTL. Both options are based on the same operation frequency of 108.4 MHz as of the present linac. Each accelerating structure will be fed by an individual RF system with a maximum pulse power of 1.6 – 1.8 MW. Besides the cavity losses, a significant beam load up to 1.3 MW for the complete HE linac is considered.

MODERNISATION OF THE EXISTING POST STRIPPER RF SYSTEMS

Currently, five pulsed high power amplifiers (HPA) equipped with RS 2074HF tubes feed the five Alvarez tanks. A maximum pulse power around 1.7 MW can be achieved for duty cycles up to about 20 % [4]. The HPA stages are fed by four 1 MVA plate power supplies connected directly to the 20 kV power network.

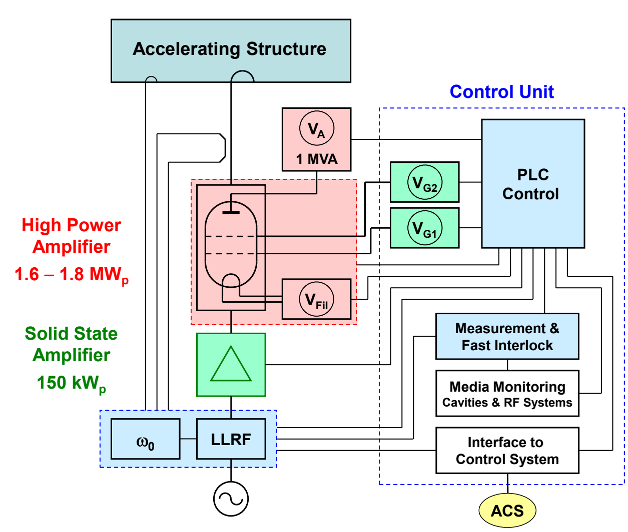

Figure 1: Simplified block diagram of the post stripper RF systems after modernisation (ACS ≡ Accelerator Control System).

The driver amplifiers – also used for the single gap resonators and for some bunchers – are built of 50 W and 300 W solid state amplifiers followed by 10 kW (RS 2024CW) and 160 kW (RS 1084CJ) tube stages. Problems arose on the procurement of spare parts for those old working horses of the UNILAC.

The following modernisations are planned (Fig. 1):

- The old control components of the HPA stages will be substituted by modern PLCs. New fast measurement and interlock systems and commercial control grid power supplies will replace the old equipment.
- The new components will be installed in separate control racks comprising also the LLRF systems and the interface to the accelerator control system.
- Replacement of the old driver amplifiers by new 120 – 150 kW solid state amplifiers. A call for tender for a prototype is in preparation.
- The original relay based control of the 1 MVA anode power supplies will be substituted by modern PLC systems.
- Substitution of the resonance tuning circuits and of the LLRF systems by new developments.

This modularised concept allows for substitution of individual subsystems more easily. Preparations and developments are in progress and ordering of components is just starting. A stepwise modernisation is planned during longer shutdown periods of the GSI accelerators in the coming years. A majority of the activities are planned for 2015 to 2017, whereas the substitution of the drivers and of the LLRF systems will proceed beyond 2017.

1.8 MW AMPLIFIER PROTOTYPE

On a long-term schedule, a replacement of the existing high power amplifiers is considered. The development and manufacturing of a 1.8 MW amplifier prototype was ordered to Thales Electron Devices, based on a Thales TH 558SC tetrode, which is widely used worldwide for medium- and short-wave broadcast transmitters as well as for scientific applications. Thus, there is no known risk concerning the long-term availability of this tube for the coming decades. Like the RS 2074HF, the TH 558SC has a thoriated tungsten mesh filament, pyrolytic graphite grids, and a max. anode dissipation power of 500 kW.

A sketch of the new amplifier cavity is shown in Fig. 2. The cavity is designed in grounded cathode configuration. The input resonator is closed by a short circuit piston and driven by direct coupling of the input coaxial line, while input matching is provided by adjusting the length of the coaxial transformer. Input circuit tuning is achieved by an adjustable stub line. The output circuit has a folded resonator with a square shaped outer conductor and a 50 Ω λ/4 output coaxial transformer, directly coupled to the resonator. Output tuning is provided by a short circuit piston. Damping devices are foreseen around the main ceramics insulator and on the tuning short circuit to prevent occurrence of parasitic oscillations. The three

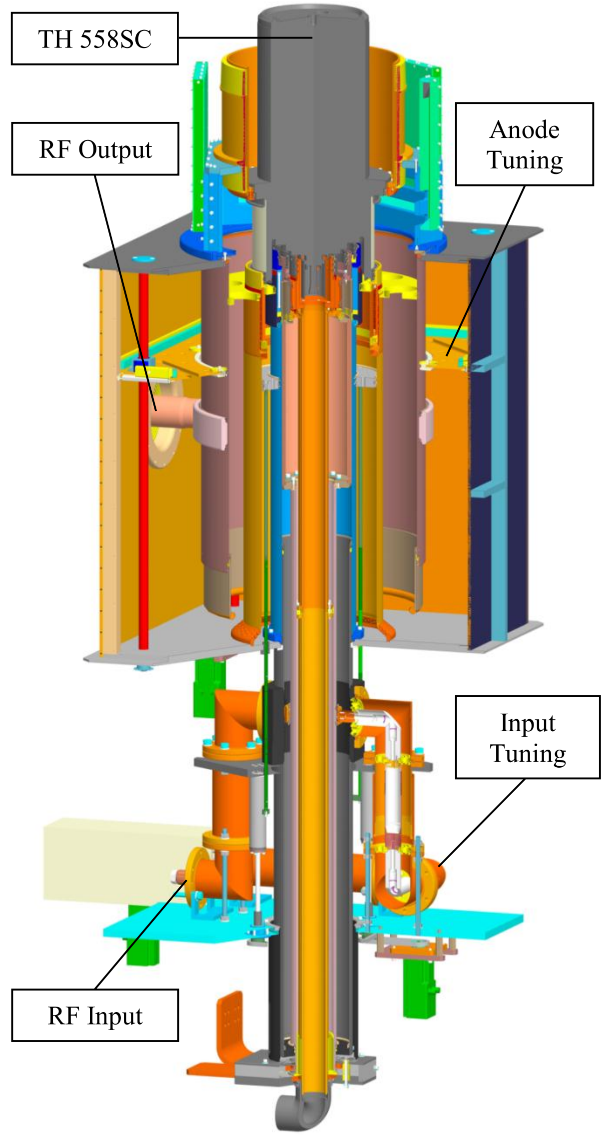

Figure 2: Sketch of the new 1.8 MW high power amplifier cavity prototype for TH 558SC designed by Thales (by courtesy of Thales Electron Devices, Thonon, France).

main tuning systems (except the G1 – G2 circuit) will be equipped with DC motors to allow for fast tuning during routine operation. The amplifier will be installed on a closed support structure housing also a commercial DC filament power supply.

Delivery of the amplifier to GSI is planned for the second half of 2015. A test bench will be prepared at the UNILAC RF gallery allowing operation of the new amplifier either on a water dummy load or on one of the Alvarez cavities. An existing coaxial line switch will be used for switching between both loads. The 150 kW solid state amplifier prototype (see previous section) will be used as driver. A second feeder line of one of the modernised 1 MVA power supplies will be used to supply the anode power at 24 kV (reduction to 18 kV for testing possible). A separate control rack constructed in the same way as for the modernised existing amplifiers will be prepared for test bench operation (Fig. 1).

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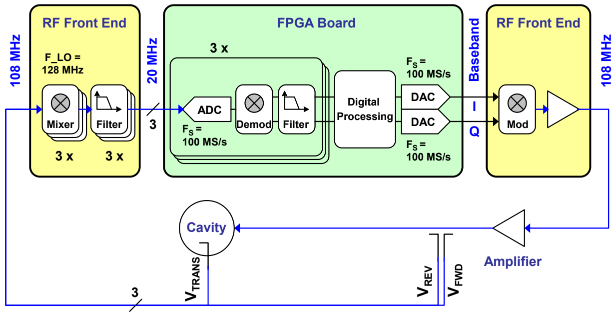

Figure 3: Signal processing in the Ampegon d-LLRF system [7].

D-LLRF SYSTEM TESTS

A commercial digital low-level RF (d-LLRF) system developed by Ampegon (former brand Thomson Broadcast) for 217 MHz linac RF systems for particle therapy facilities [7] was adapted by Ampegon to 108 MHz by modification of the RF front end. The modified system was integrated into a 160 kW amplifier at GSI and was tested for RF amplitude and phase control of a single-gap resonator at the UNILAC. The signal processing is shown in Fig. 3. The RF signal from a cavity pick-up is down-mixed to an intermediate frequency of 20 MHz. The IF signal is digitized at 100 MS/s with a 16 bit ADC. The sampled signal is demodulated and low-pass filtered by a digital signal processing block based on an ALTERA FPGA, generating a pair of I and Q signals. A digital PI controller is used to produce new baseband I and Q set values which are converted to analog signals by a dual 14 bit DAC. An integrated quadrature modulator converts the IQ signals to the RF input signal for the RF amplifier.

Due to the highly non-linear characteristics of the old R&S broadcast amplifiers used in the GSI 160 kW amplifiers, no stable operation could be achieved with the d-LLRF system at the beginning of the tests. After increasing the bias current of the transistor stages as well as of the tube stages of the GSI amplifiers, stable operation was possible within a limited amplitude range around 30 % to 55 % of the maximum amplifier RF level.

Beam tests with 1.3 mA $^{181}Ta^{24+}$ beams were performed (Fig. 4). Highest operation stability could be achieved with an integrator time constant of the PI controller of $Ti = 80$ µs. Due to this long time constant, the beam loading of the 100 µs long beam pulses could not be compensated (Fig. 4a). Better beam loading compensation as well as smaller amplitude deviations were achieved with a time constant of $Ti = 10$ µs (Fig. 4b), but for the price of unwanted oscillations and significant overshooting at the rising edges of the RF pulses.

As a conclusion, the Ampegon d-LLRF system could be successfully tested at GSI but some improvements are necessary. Amplitude and phase control should be separated by using a CORDIC and two independent controllers instead of the IQ vector controller. A look-up table for the amplifier characteristics should be implemented. Further tests of an improved system are planned.

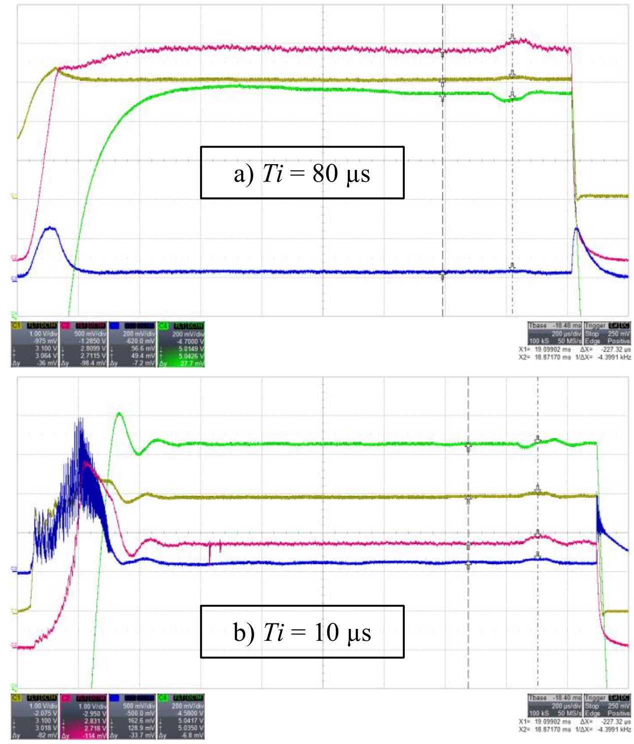

Figure 4: Measured demodulated RF signals at different settings of the FPGA based PI controller (see text). CH1 (yellow): forward power 300 W pre-driver, CH2 (red): forward power to accelerator cavity, CH3 (blue): reverse power, CH4 (green): cavity amplitude (zoom, 0.2 V/div at 5 V signal amplitude). CH3 is measured by different RF detectors in plots a) and b). The right vertical line cursor marks the centre position of the 100 µs beam pulse.

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