A NEW RF STATION FOR THE ELSA STRETCHER RING*

Manuel Schedler, Andreas Dieckmann, Philipp Hänisch, Wolfgang Hillert
ELSA, University of Bonn, Germany

Abstract

At the Electron Stretcher Facility ELSA of Bonn University, an increase of the maximum stored beam current from 20 mA to 200 mA is planned. The storage ring operates applying a fast energy ramp of 6 GeV/s from 1.2 GeV to 3.2 GeV and afterwards a slow extraction over a few seconds to the hadron physics experiments. The beam current is mainly limited due to missing RF power at highest energies in order to compensate for synchrotron radiation losses.

The current stretcher ring's RF station is based on a single 200 kW klystron driving two 5-cell PETRA type cavities. To achieve the desired beam current at maximum energy two additional 7-cell PETRA type cavities, drivin by a second klystron, will be installed. With this upgrade, sufficient beam lifetime for slow beam extraction will be provided and thus ensure an adequate duty cycle of the external beam current. The general setup of the new RF station as well as the changes in operation when switching from one to two stations will be presented.

THE ELECTRON STRETCHER ACCELERATOR – ELSA

ELSA is a three-stage electron accelerator. One of the two linear accelerators is used to inject an electron beam of 20 MeV into a booster synchrotron to gain an energy of typically 1.2 GeV. The beam can be accumulated and stored in the 164.4 m long stretcher ring, accelerated to a maximum energy of 3.2 GeV and, finally, slowly extracted to the hadron physics experiments using resonance extraction methods [1]. Figure 1 gives an overview of the ELSA facility including injector chain, stretcher ring and user experiments. The main operating parameters of the accelerator are summarized in Table 1.

On the fast energy ramp of typically 6 GeV/s in the stretcher ring fast changing beamloading effects lead to fast changing cavity voltages and phases. Figure 2 shows a typical post-acceleration cycle of the stretcher ring. To compensate for synchrotron radiation losses even at highest beam energies and intensities a new RF station is required. In addition, this station will allow to maintain the required overvoltage factor and lifetimes which of course have to be significantly greater than the extraction time of a few seconds to deliver a high quality and high intensity electron beam to the hadron physics experiments.

* Work supported by the DFG within the SFB/TR 16

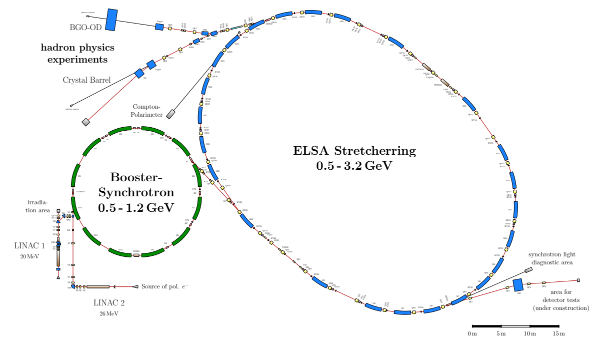

Figure 1: The Electron-Stretcher-Accelerator Facility ELSA

Table 1: Main Operating Parameters of the ELSA Stretcher Ring

Parameter	**Value**
Length	164.4 m
RF	499.669 MHz
Bunch spacing	2 ns
Harmonic number h	274
Filled buckets	274
Revolution frequency f_{rev}	1.8236 MHz
Beam energy E	1.2 GeV to 3.2 GeV
Beam current	20 mA to 200 mA
Ramping speed	$\leq$ 6 GeV/s
Injection rate	50 Hz
Momentum compaction factor α_c	0.0601

OVERVIEW AND SETUP OF THE NEW RF STATION

General Setup

The new RF station is based on two 7-cell PETRA type normal conducting RF cavities with a shunt impedance of 23 MΩ driven by a single klystron amplifier. The RF frequency is about 500 MHz as for the existing RF station. A magic T is used to split the amplified high power RF signal into two equivalent components in a WR1800 waveguide

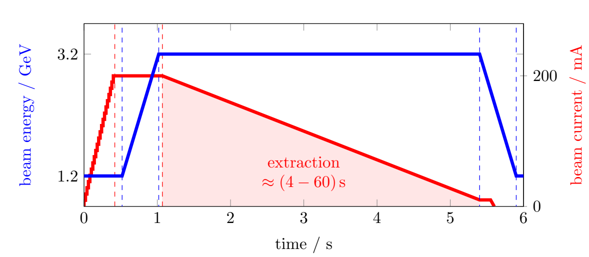

Figure 2: Post-acceleration mode of the ELSA stretcher ring.

system. Figure 3 shows the schematics of the new RF station and its control which is based on a 9-channel digital LLRF system for stabilizing cavity fields and phases. Two probe signals from two different cavity cells are used to monitor the acceleration voltage per cavity and to build up tuner loops as well as RF voltage and phase loop.

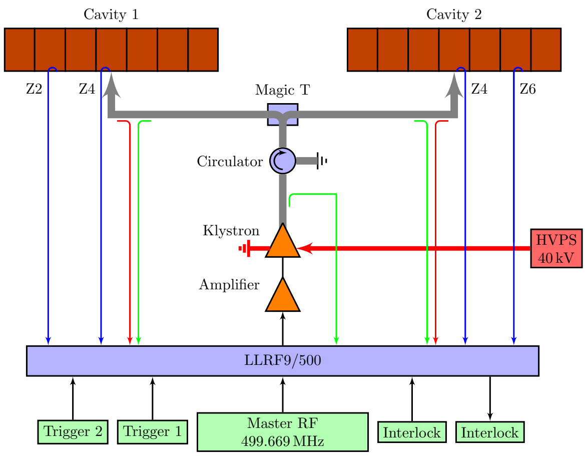

Figure 3: Schematic of the new RF station including two 7-cell PETRA type RF cavities.

High Voltage Power Supply

The high voltage power supply of the klystron amplifier F-2055, manufactured by Thomson-CSF, is based on a 6-pulse bridge connected to a high voltage transformer and a rectifier chain. A capacitor in the rectified high voltage path, connected to the electron gun of the klystron, is used to suppress AC contributions by −48 dB. Figure 4 shows the layout of the klystron power supply including 6-pulse bridge, transformer, rectifier and filter array. The filter capacitance has been designed to store less energy than klystron damage threshold of 20 W s which allows to operate the klystron without a crow bar chain. A fast interlock system inhibiting the triggers for the 6-pulse bridge ensures the fast shutdown in case of voltage breakdown.

Low Level RF System

To operate the RF station a new LLRF system is required. A Dimtel LLRF9/500 system [2] which is already used at the first RF station of ELSA has been chosen for running the new RF station in parallel. This system has 9 analog RF inputs to monitor cavity voltages and phases and directional coupler signals from the RF waveguides. A fully FPGA-based digital approach of data processing allows the integration of a proportional and integral feedback loop to control the accelerating voltage of the RF station. The RF output of the LLRF directly drives the first amplifier stage connected to the klystron. Based on the error suppression of the LLRF system at low excitation frequencies [2], shown in Figure 5, a considerably high voltage ripple at 300 Hz of the klystron power supply can be accepted, which will be rejected by the LLRF by about −40 dB.

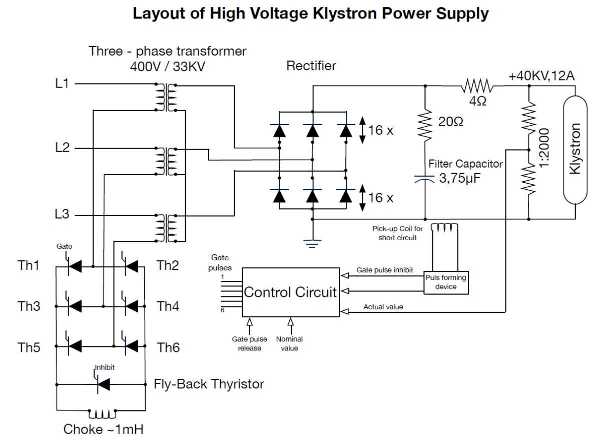

Figure 4: Schematic of the klystron high voltage power supply using a 6-pulse bridge.

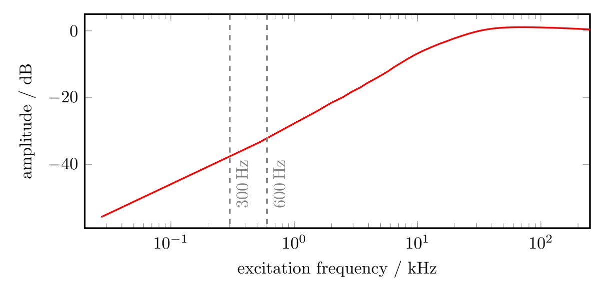

Figure 5: Error suppression of the LLRF system measured with the 5-cell cavity RF station.

OPERATION CONDITIONS

Optimization of Power Consumption

Since both RF stations of the stretcher ring have different types of cavities the operation of both stations in parallel has to be optimized to achieve the maximum accelerating voltage at minimum RF and electrical power consumption. Thus, the available power for beamloading compensation and so the maximum storable electron beam intensity is maximized. The existing RF station consists of two 5-cell PETRA type cavities with a shunt impedance of 15 MΩ whereas the new cavities have a shunt impedance of 23 MΩ.

To generate the RF accelerating voltage U using two RF stations with two cavities of shunt impedance R_i each, the total power $P = P_1 + P_2$ is needed to generate

$$U = 2 \cdot \sqrt{(P - P_2) \cdot R_1} + 2 \cdot \sqrt{P_2 \cdot R_2}. \tag{1}$$

The minimum power consumption is achieved when the acceleration voltages are generated by the contributions

$$U_1 = \frac{U}{1 + \frac{R_2}{R_1}} \tag{2}$$

$$U_2 = \frac{U}{1 + \frac{R_1}{R_2}}. \tag{3}$$

Following this ansatz the RF can be operated with maximum efficiency and maximum beam current when using non-equal cavity voltage splitting.

Beam Lifetime and Maximum Beam Current

The required synchrotron frequency and thus the required overvoltage factor depend on the desired lifetime at extraction energies. Figure 6 shows the achievable quantum lifetime in the stretcher ring depending on beam energy for various synchrotron frequencies f_s. Depending on the extraction time and beam energy the synchrontron frequency and thus the lifetime has to be adjusted accordingly.

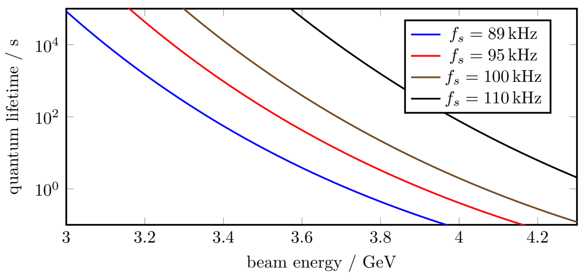

Figure 6: Quantum lifetime of the electron beam for different beam energies and synchrotron frequencies in the stretcher ring.

Due to the required compensation of synchrotron radiation losses the maximum storable beam intensity is limited by the maximum available RF power. Figure 7 illustrates this limitation calculated for the old setup and for two different operation modes of the new setup. With the old setup the beam energy is limited to a maximum of about 3.3 GeV whereas operation of the stretcher ring with two stations allows to reach the design energy of 3.5 GeV with intensities of up to 100 mA. In addition, the target value of 200 mA at a beam energy of 3.2 GeV will be achieved for hadron physics experiments.

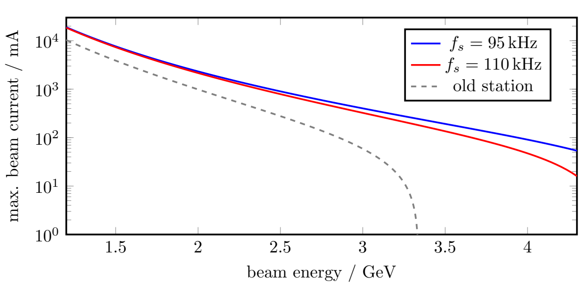

Figure 7: RF power limited maximum beam current of the stretcher ring with the new RF station.

Higher Order Modes and Beam Instabilities

Figure 8 shows the calculated impedance spectrum of a 7-cell PETRA type cavity using CST Particle Studio. Besides the fundamental mode at 500 MHz used for particle acceleration a couple of higher order modes show up at higher resonance frequencies with non-vanishing longitudinal shunt impedances. Especially mode TM_{021} has a shunt impedance in the same order of magnitude as the fundamental mode. This mode is as well prominent for the 5-cell cavities causing longitudinal multi-bunch instabilities in the stretcher ring which have to be suppressed using a state-of-the-art bunch-by-bunch feedback system [3].

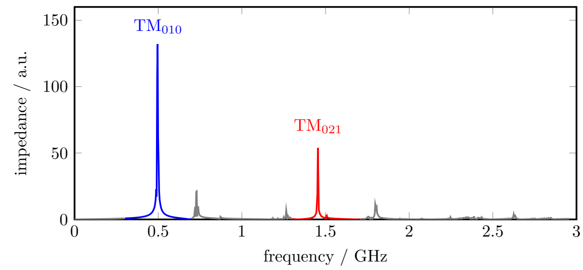

Figure 8: Calculated impedance spectrum of a 7-cell PETRA type RF cavity using CST Microwave Studio.

As a passive countermeasure to fight against beam instabilities, a new water cooling system of the RF cavities will be installed in order to stabilize and control the cavity's temperature [4]. This allows for changing the resonance frequencies of the HOMs whereas the tuners keep the resonance frequency of the fundamental mode at the design value. This method can be used to minimize the instability driving effects of the RF cavities.

A water cooling bypass to the cavities in addition with a three-way mixing valve allows for changing the amount of fresh cool water feeded to the cavity path and to set the temperature of the cavities to a less harmfull region.

CONCLUSION

The new RF station using two 7-cell PETRA type RF cavities will allow to operate the stretcher ring at beam currents of up to 200 mA in post-acceleration mode with energies of up to 3.2 GeV. The new RF station will be set up including a new HVPS and klystron, a digital LLRF system and a magic T RF power splitter to drive the two cavities.

The HOMs of the two cavities could cause longitudinal instabilities in the stretcher ring which will be suppressed via a state-of-the-art bunch-by-bunch feedback system in conjunction with a temperature control and stabilization of the cavities.

REFERENCES

[1] W. Hillert, The Bonn Electron Stretcher Accelerator ELSA: Past and future, *Eur.Phys.J.* ***A28S1**, 139 (2006)*

[2] M. Schedler, et al., A new digital LLRF system for a fast ramping storage ring, *IPAC'14 Conf. Proc. (2014) 2418*

[3] M. Schedler, et al., Broad and Narrow Band Feedback Systems at ELSA, *IPAC'13 Conf. Proc. (2013) 2714*

[4] D. Sauerland, et al., Amplitude, Phase and Temperature Stabilization of the ELSA RF System, *IPAC'13 Conf. Proc. (2013) 2717*