BUNCH COMPRESSION FOR FAIR

P. Hülsmann, R. Balss, U. Laier, H. Klingbeil
GSI, Gesellschaft für Schwerionenforschung, Planckstrasse 1, D-64291 Darmstadt

Abstract

To feed the production targets of FAIR with very short bunches (pulse durations of not more than 50 ns are envisaged) demanding rf-systems for bunch compression are required in SIS18 and SIS100. But also the opposite process, namely debunching, is required in the collector ring (CR). Bunch compression as well as debunching will be done by fast bunch rotation. Due to space restrictions both rf-systems must be able to generate a very high field gradient of 33 kV/m at very low frequencies. Such high field gradients can be realised easily using magnetic alloy (MA) cavities, since their saturation field strength is about ten times higher compared to NiZn-ferrites. For SIS18 an MA bunch compressor unit, which generates the required 40 kV at 800 kHz and 1200 kHz, has already been realized as a forerunner for the required FAIR-systems.

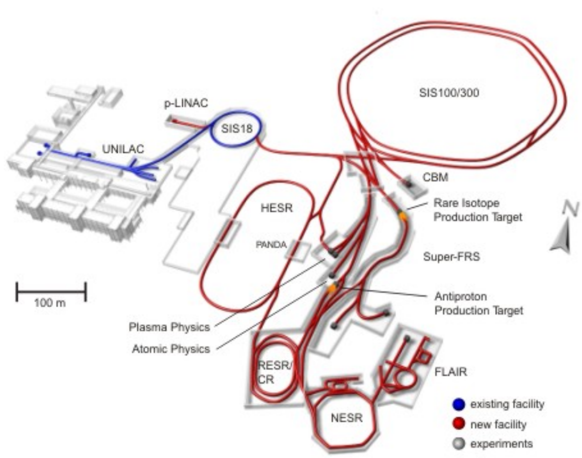

Figure 1: A schematic overview over the FAIR-facility.

INTRODUCTION

The GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt is planning a new powerful facility named FAIR (**F**acility for **A**ntiprotons and **I**on **R**esearch) [1] which includes an upgrade of the old synchrotron SIS18 and the construction of a new synchrotron ring SIS100 (see Fig. 1). For storage of exotic nuclei, for antiproton production and for plasma physics at the new facility short and intensive ion bunches in the region from 400 MeV/u to 2,7 GeV/u for U^{28+} and 29 GeV for Protons are required with a pulse length of 30-50 ns. It is planned, that SIS100 should provide 3×10^{11} heavy ions per second and 2.5×10^{13} Protons per pulse every 5 seconds for antiproton production.

The rf acceleration system is designed for a total rf peak voltage of about 400 kV, which is required to provide the necessary acceleration voltage per turn in the fast ramping mode of 4 T/s. For operation at harmonic number h=10 in the frequency range between 1.1 MHz and 2.7 MHz, ten rf buckets are generated, and with four SIS18 booster cycles eight of these buckets will be filled. Two buckets are left empty to introduce an adequate free space for operation of injection- and extraction kicker modules. An rf barrier bucket system has to combine the eight bunches into one long bunch in a first step, which in a second step is transformed by the bunch compression system into a single bunch with pulse length of about 30 ns to 50 ns by a fast 90° rotation in the longitudinal phase space (see Fig. 2). This manipulation is required to prepare the SIS100 proton or ion beams for production of a single short bunch of either radioactive ions or antiprotons for injection into the collector ring CR. In the CR the compressed bunch of e.g. exotic nuclei has to be debunched again by fast bunch rotation in order to allow a further treatment of the beam.

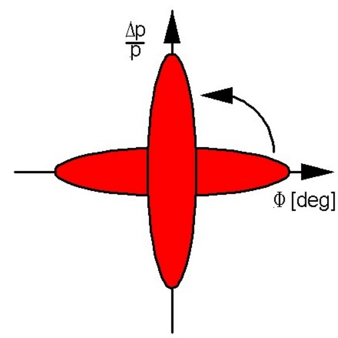

Figure 2: Bunch compression by fast bunch rotation. The primarily bunch in the horizontal position will be rotated by 90° into an upright position.

For the rotation process in SIS100 finally sixteen, 1.2 m long cavities are foreseen occupying a full straight synchrotron section. Each cavity is designed for a peak voltage of 40 kV and an RF pulse length of up to 500 µs. For operation with a very short duty cycle, air cooled cavities with magnetic alloy ring cores are foreseen.

REQUIREMENTS

The SIS100 bunch compression system as well as the CR-debuncher will be based on the experience with the SIS18 bunch compressor project [3] where the first prototype is presently available at GSI. The desired total voltage for the final bunch compression in SIS100 is 640 kV after completion of stage B; during stage A 360 kV will be available only (FAIR will be realized in two consecutive stages named A and B). For bunch rotation, an effective pulse length of 500 µs is required. Taking the tetrode preparation times into account, the RF pulse length will be significantly longer. Based on the experience with the SIS18 bunch compressor where an effective pulse length of 250 µs is achieved, the development of the SIS100 bunch compressor system has to focus on the extension of the pulse length. Furthermore, the operating frequency is lower than that of the SIS18 bunch compressor. The frequency range varies between 395 kHz and 485 kHz depending on the extraction energy which is about half of the frequency of the SIS18 bunch compressor.

The bandwidth of the cavity will be large enough to cover the full frequency range without biasing. As mentioned above, the frequency for bunch compression in SIS100 is about half of the frequency in SIS18 and therefore the shuntimpedance of the magnetic alloy ring cores will be reduced. In principle the number of ring cores has to be increased accordingly but due to the restricted space in SIS100 this seemed to be no option. One cavity is restricted to a length of 1.2 m and thus a maximum number of 20 ring cores can be housed. A maximum gap voltage of 40 kV per cavity is required and therefore 16 cavities are foreseen for bunch compression in the final construction stage. During FAIR stage A, the number of bunch compressor systems is reduced to 9. This will lead to restrictions for the achievable bunch length.

Compared to the SIS100 bunch compressor the situation for the collector ring debuncher is slightly different. For this rf system the operating frequency is in the frequency range between 1.17 MHz and 1.37 MHz and the voltage requirement is 40 kV for the pulsed operation (duty cycle $5{\cdot}10^{-4}$). But a special challenge is the continuous operation with 2 kV per cavity unit for adiabatically debunching the beam [2,4,5].

COMPRESSOR RF SYSTEM FOR SIS18

The SIS18 Bunch Compressor Cavity is filled with 2x10 magnetic alloy ring cores (VitroVac 6030F, an cobalt based amorphous magnetic alloy, see Fig. 3) and provides 42 kV gap voltage at an operating frequency of 0.8 MHz and 1.2 MHz (harmonic number h=1 at extraction level) [1]. System challenges were for instance the very short rise time (< 10 µs) of the rf voltage and thus the development of a very fast MOSFET switch for shorting the gap during acceleration (switching time ≤ 10 µs).

Figure 3: The bunch compressor cavity loaded by 20 MA-ring-cores (VitroVAC 6030F). The box on top of the cavity contains the adjustable gap capacitors to tune the cavity.

The rf power amplifier works in A-operation and feeds the cavity in push-pull mode using two Siemens RS 2054 SK tubes (120 kW cw anode dissipation power). During the rf pulse the anode dissipation power of both tubes is about 600 kW (tube working point 26 kV; 19 A, pulse duration 500 µs).

Figure 4 shows the original tube socket for the Siemens RS 2054 SK tube which is equipped with a 250 nF film capacitor in order to ground the unwanted rf. This solution has led to an instability and some significant changes of the tube socket construction were necessary to eliminate the problem.

The solution is shown in Fig. 5. Fifty barrel style ceramic capacitors have been arranged between two large copper plates. The upper copper plate is connected to the screen grid and the lower plate is connected to the ground plate of the tube socket. This construction has, compared to the film capacitor, a very low inductance, since the instability was caused by a screen grid shunt capacitance which becomes inductive at 2.2 MHz. Together with the intrinsic plate capacitance in the tube socket the shunt capacitor formed a tube socket resonator with a resonance frequency of 7.5 MHz. The oscillator was excited by fluctuations of the vacuum tube DC current (A-operation).

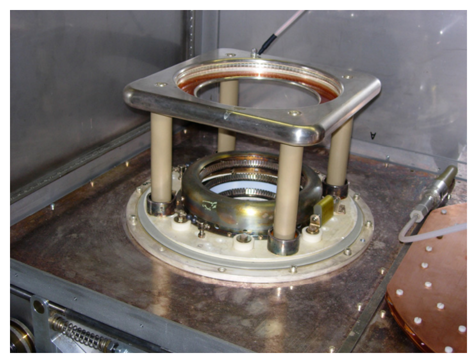

Figure 4: The original tube socket for the RS 2054 SK tetrode with the film shunt capacitor

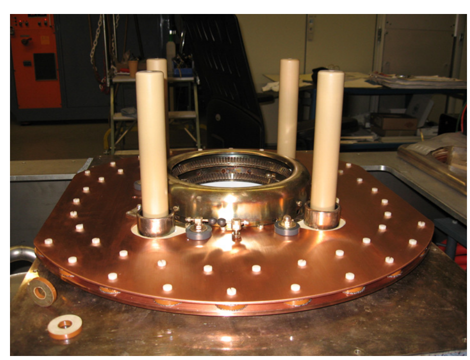

Figure 5: The modified tube socket equipped with fifty 5 nF barrel style capacitors

Figure 6 shows the compressor cavity with power amplifier already installed in the SIS18 tunnel. The supply unit for the power amplifier is located about 150 m away from the cavity-power-amplifier-installation in the tunnel.

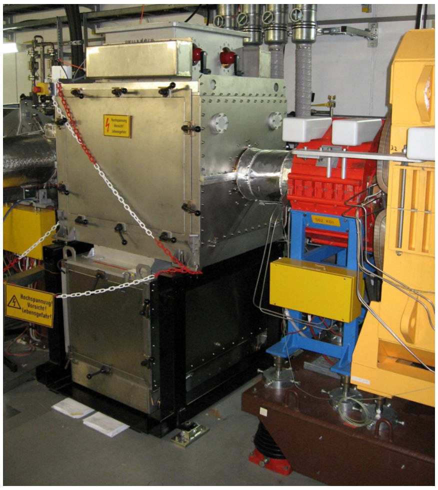

Figure 6: The cavity and power amplifier already installed in the SIS18-tunnel

Figure 7 shows the supply unit consisting of anode, control-grid, screen-grid and cathode heating supply. Furthermore the supply rack is also equipped with the low level electronics consisting of the amplitude and phase control and the data logging system. A Siemens S7 PLC manages the step up and step down sequences of the tubes, monitors and handles the interlock signals.

Figure 7: The supply unit with the data logging system and the low level electronics

FIRST MEASUREMENTS WITH BEAM

On January 16th 2009 first beam experiments with the compressor RF system have been performed with Ar^{18+} ions at injection level and harmonic number h=4. The beam energy and harmonic number were chosen in such a way to avoid sophisticated bunch merging (4 bunches into a single bunch) while keeping the RF frequency within the operating parameters of the bunch compressor.

During the experiment, the influence of different parameters as for example the amplitude and phase of the gap voltage as well as the pulse duration on the beam were evaluated.

Figures 8 and 9 show the measured beam profile (Σ signal of a BPM) before (3 kV gap voltage) and after the compression (33 kV gap voltage, about 100 µs RF pulse duration). A first preliminary evaluation of the measured data shows a compression factor of roughly 3 as expected for the mentioned ratio of gap voltages, since the ratio of the initial- to the final bunchlength is equal to the square root of the ratio of the final voltage to the initial voltage

$$\frac{\sigma_i}{\sigma_f} = \sqrt{\frac{V_f}{V_i}}, \tag{1}$$

in the case space charge is negligible [6].

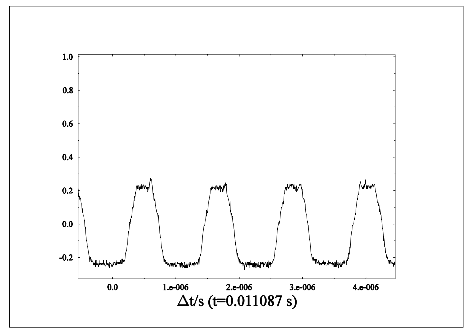

Figure 8: Beam signal before bunch-rotation (t refers to the time in the cycle)

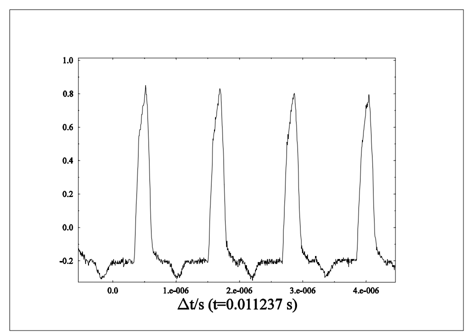

Figure 9: Beam signal after the 90° bunch-rotation.

REFERENCES

[1] 'FAIR Technical Design Report', GSI Darmstadt (2008).

[2] U. Laier, P. Hülsmann, K.P. Ningel, G. Schreiber, 'Design of an MA based RF System for the Collector ring at FAIR' Proceedings of the PAC'09, Vancouver (2009), in preparation

[3] P. Hülsmann, G. Hutter, W. Vinzenz, 'The Bunch Compressor System for SIS18 at GSI', Proceedings of the EPAC'04, Lucerne (2004).

[4] U. Laier, 'Technical Concept CR Debuncher', rev. 1.20, GSI Darmstadt (2009).

[5] J. Hottenbacher, P. vom Stein, 'FAIR CR Cavity Study Final Report', ACCEL Bergisch Gladbach (2006).

[6] G. Franchetti, I. Hofmann, and G. Rumolo, 'Effect of space charge on bunch compression near the transition', Physical Review Special Topics, Accelerators and Beams, Volume 3, 084201 (2000).