DESIGN OF AN MA BASED RF SYSTEM FOR THE COLLECTOR RING AT FAIR

U. Laier, P. Hülsmann, K.P. Ningel, G. Schreiber
GSI, Darmstadt, Germany.

Abstract

The 'Facility for Antiproton and Ion Research' (FAIR) [1] will be realized in the scope of a large international collaboration at the site of the 'GSI Helmholtzzentrum für Schwerionenforschung GmbH' (Darmstadt, Germany). One of the FAIR storage rings is the collector ring (CR) [2] whose main purpose is to allow a fast cooling of secondary beams (rare isotopes and antiprotons). The RF system of the collector ring has to allow pulsed operation (40kV, duty cycle $5\cdot10^{-4}$) as well as continuous operation (2kV) in the frequency range from 1.17 to 1.37MHz.

The detailed conceptual design of this RF system is introduced here. It will be based (similar to the existing RF system 'SIS18 bunch compressor' [3]) on two inductively loaded quarter wavelength coaxial resonators operating on a common ceramic gap. The resonator will be loaded with twelve ring cores of a cobalt based amorphous magnetic alloy (VitroVac6030F); it will be cooled by forced air. The cavity will be driven by a push-pull amplifier operated in class A consisting of two TH555A tetrodes that will be coupled inductively to the cavity.

REQUIREMENTS

The RF system will be operated in the frequency range between 1.17 and 1.37MHz. It will be used directly after injection into the CR to reduce the momentum spread of the particles (ions as well as antiprotons) by performing a fast quarter rotation in phase space (21 to 40kV, pulse length 100-500µs, duty cycle $<5\cdot10^{-4}$). Afterwards the beam is adiabatically debunched (<2kV, <150ms) before stochastic cooling is applied. The RF system will also be used to allow an adiabatic rebunching (<1kV, <130ms) prior to extraction.

Therefore, the RF system has to be operated in pulsed as well as continuous operation. A total of five RF systems will be installed in the CR with the option of an additional amount of five systems. The bunch compression system presented here is only one RF system required for bunch compression at FAIR. An overview concerning all FAIR compression systems is given in [4].

CAVITY

The cavity (see Figure 1) with a total length of 1m will be built as two inductively loaded coaxial quarter wavelength resonators operating on a common gap. The design presented here is close to another RF system [3] that has been put into operation at GSI.

Only the beam pipe with an inner diameter of 150mm and the ceramic gap (Al_2O_3) will be part of the vacuum system of the CR. Around the beam pipe ring cores consisting of an amorphous magnetic alloy (MA) will be built on both sides of the gap to implement the inductive loading of the resonator. The whole cavity will be enclosed in a rectangular housing made of stainless steel. Since no fast change in the resonance frequency is required (about 60s are available for a change of the operating frequency) the tuning of the cavity will be performed by two remotely controllable capacitors each connected by a bus bar from one side of the gap to ground potential.

These bus bars will also be used to connect two types of gap switches, namely gap relays which will be used to allow a long term short circuit of the gap and fast MOSFET switches that allow a cycle to cycle switching.

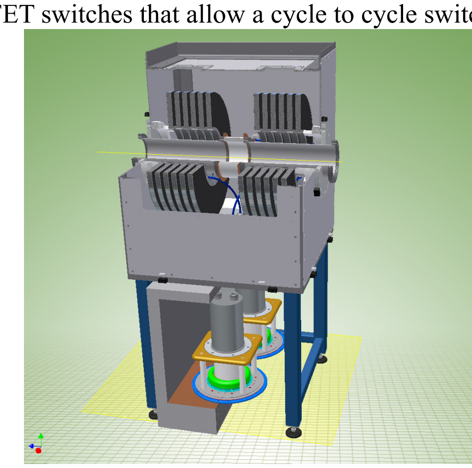

Figure 1: Sketch of the CR debuncher cavity including amplifier.

The amplifier will be coupled inductively to the cavity.

A single feedthrough into the cavity housing will be used to connect the DC voltage from the anode supply.

Starting from this feedthrough, two coupling loops each surrounding all ring cores of one half of the cavity will be connected to the tubes.

MA Ring Core Properties

The performance of the cavity is dominated by the properties of the ring core material making the selection of ring core material and dimensions essential when designing the cavity. The cavity presented here will rely on VitroVac6030F, an amorphous cobalt based magnetic alloy manufactured by Vacuumschmelze. It is planned to use 17µm thick MA ribbon isolated by a magnesium oxide layer. This ribbon will be wound on an inner ring composed of stainless steel forming so called ring cores with an inner radius of 145mm and an outer radius of 313mm. These inner rings of all ring cores on one side of the gap will be connected electrically, thereby creating a potential free zone between the beam pipe and the ring cores that will be used for the coupling loops. It has an fshape of the hysteresis loop and combines a fairly high µQf value (about 4.1GHz in the given frequency range), a reasonable inductivity (about 4.7µH) and sufficiently high values concerning the saturation induction (about 1T). Table 1 gives an overview regarding the most important parameters of the ring cores. The values presented here result from impedance measurements covering the frequency range of interest that were performed at GSI on several full size ring cores in a dedicated resonator.

Table 1: Main properties of the magnetic alloy ring cores. Wherever two values are given here, the first corresponds to 1.17MHz, the second to 1.37MHz

Material	VitroVac6030F
Thickness of MA ribbon (µm)	17
Thickness of isolation (µm)	2
Inner radius r_{in} (mm)	145
Outer radius r_{out} (mm)	313
Width h (mm)	25
Flux area (m^2)	$4.3 \cdot 10^{-3}$
Filling factor η	0.70
Serial inductivity L_s (µH)	4.2–4.0
Serial resistance R_s (Ω)	10.5-13.5
Parallel inductivity L_p (µH)	4.7
Parallel resistance R_p (Ω)	101
Q-value	2.9-2.5
$\mu_p Qf$ value (GHz)	4.1

Electrical Design

A total number of 12 ring cores will be used, six on each side of the gap. This choice fixes the shunt impedance of each cavity half to 600Ω, the inductivity amounts to 28.2µH, allowing a maximum total capacitance of the whole cavity of about 240pF.

Regarding the maximum gap voltage of 40kV, a maximum magnetic induction of B_{RF}=0.23T results. The ring cores will also be subject to a DC induction of B_{DC}=0.17T caused by the DC current flowing through the coupling loops. Therefore, the maximum induction in the ring cores stays well below 0.6T ensuring, that the MA material is operated within the linear part of its hysteresis loop.

To evaluate the behaviour of the cavity, a simulation based on lumped elements has been performed with PSPICE. Here, each ring core has been modelled by a series connection of R_s and L_s. The simulation also takes radial capacitances of the ring cores, the intra ring core capacitances and capacitances between the ring cores and the cavity housing as well as the gap capacitance and the switches into account. As a result of these simulations, each cavity half can be described by a parallel equivalent circuit whose impedance is sketched in Table 2.

The total averaged power (pulsed and c.w. operation) dissipated in the cavity amounts to about 2kW (165W per ring core). This heat load will be removed by forced air cooling.

Table 2: Basic Properties of the CR debuncher cavity. Shown here are the parallel inductivity, and the shunt impedance of one cavity half. The capacitance given here refers to the gap capacitance (including spare capacitances).

	f=1.17MHz	f=1.37MHz
Parallel inductivity (µH)	28.2	28.2
Shunt resistance (Ω)	600	598
Capacitance (pF)	327	239
Unloaded Q-factor	2.88	2.46

AMPLIFIER

The amplifier will consist of two tetrodes (THALES TH555A, 250kW anode dissipation) operating in push pull configuration on both halves of the cavity. The tubes will be operated in class A or AB at two different working points, one for pulsed and one for continuous operation. The shifting between both types of operation will be done by a fast transition of the control grid DC voltage. Similar to the solution for the SIS18 bunch compressor, this shifting will be done by two voltage supplies. In case of pulsed operation, a first voltage supply will be connected by means of a fast semiconductor switch in parallel to a series connection between the second one which is responsible for c.w. operation and a load resistor (see Figure 2).

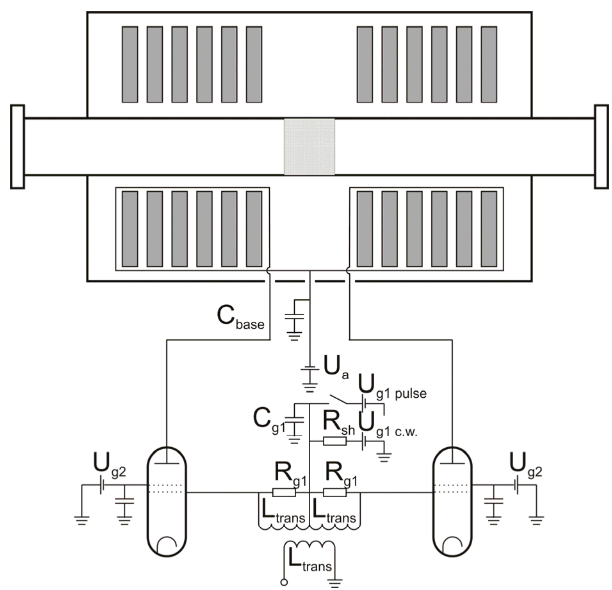

Figure 2: Scheme of the CR debuncher RF system Shown here is the cavity using twelve ring cores, the coupling loops, the push-pull amplifier and some aspects of the supply unit.

A driver amplifier (2kW) is currently developed that will activate the control grids of both tubes via a symmetrical input transformer with RF-grounded middle tap on the secondary side. The inductivity of this input transformer (8µH) in conjunction with the parallel resistors (100Ω) ensures impedance matching of the input impedance of the tubes to the driver amplifier.

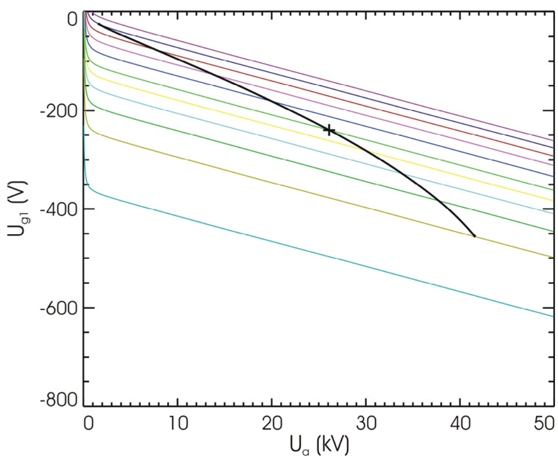

Figure 3: Shown here are the constant current lines of a TH555A (control grid voltage versus anode voltage). Each colour represents a different constant current line (2.2A to 86A). Marked in black is the load line of the tube in pulsed operation (1.17MHz, 40kV).

Based on a five parameter fit to the characteristic curves of the TH555A a mathematical model to describe the tube was developed, this model was used to perform analytical calculations to establish the main parameters of the amplifier. One result of these analytical calculations, namely the load line of the amplifier (impedance at working point of about 600Ω) in pulsed operation (40kV, 1.17MHz) is shown in Figure 3.

A detailed simulation of the interaction between the cavity and the amplifier including transient effects associated with the switching of the working point has been performed using PSPICE. This lumped element simulation uses the afore mentioned five parameter fit to describe the TH555A. The main results of theses simulations are shown in Table 3.

Table 3: Main properties of the amplifier. The values given here refer to one half of the cavity. The screen grid voltage amounts to 1500V.

	1.17MHz pulsed	1.17MHz c.w.
DC anode voltage (kV)	23.7	23.7
DC control grid volt. (V)	-240	-460
RF control grid volt. (V)	220	51
DC anode current (A)	39	3.2
Range of anode current (A)	11→80	1.8→5.1
Range of anode voltage (kV)	2.1→43	23→25
Cavity voltage (kV)	21	1.0
Input power (kW)	920	76
Cavity power (kW)	350	0.81
Anode diss. power (kW)	570	75
Efficiency	38%	1.1%
Ratio of 3rd harmonic with respect to the fundamental harmonic (dB)	-52	-61
Total settling time (change of working point) (μs)	<100	

The anode dissipation of the TH555A during pulsed operation exceeds the values rated for c.w. operation (250kW) by more than a factor of two, limiting this mode of operation to less than 500μs.

POWER SUPPLY UNIT

To operate the amplifier six main power supplies are required. One anode supply and one control grid supply; each of them will be used as a common supply for both tubes (see figure). In addition to these supplies, each tube will have its own screen grid and cathode supply to compensate for different load lines of both tubes and to prolong tube lifetime. All power supplies will be incorporated in one power supply unit together with a programmable logic control to allow flow control and interlock handling. The main parameters of the power supplies are listed in Table 4.

Table 4: Supply unit of the CR debuncher.

Power supply	Voltage	Current
Anode supply	10-27kV	<10A (avg.) <100A (500μs) <60A (1ms)
Screen grid supply	1-2kV	<2A
Control grid supply	50-800V	<4A
Cathode supply	0-400V	<16A

SUMMARY

The paper at hand gave an overview regarding the design of one of the FAIR synchrotron RF systems, namely the CR debuncher. Further details are given in [5,6,7,8].

REFERENCES

[1] W. Henning et al., *'FAIR Technical Baseline Report'*, GSI Darmstadt (2006).

[2] F. Nolden, K. Beckert, P. Beller, U. Blell, C. Dimopoulou, A. Dolinskii, U. Laier, G. Moritz, C. Muehle, I. Nesmiyan, C. Peschke, M. Steck, *'The Collector Ring CR of the FAIR Project'*, Proc. of the EPAC2006, Edinburgh (2006).

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

[4] P. Hülsmann, R. Balss, 'Bunch Compression for FAIR', Proceedings of the PAC'09, Vancouver (2009), in preparation.

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

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

[7] M. Kumm, H. Klingbeil, *'FAIR LLRF Control System for Cavities'*, rev. 0.6, GSI Darmstadt (2008).

[8] U. Laier, *'FAIR Beam Transfer Concept'*, rev. 1.00, GSI Darmstadt (2009).