RECENT RESULTS OF THE HESR RF SYSTEM

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Abstract

The FAIR complex (Facility for Antiprotons and Ion Research) will be built in different stages. Due to the postponed RESR in the first stage, both RF-cavities of the HESR have to operate in different modes to achieve the required beam quantity and quality. The RF-system of the HESR will now consists of two identical cavities with a common low-level RF control (LLRF). Both cavities will be driven by low noise solid state amplifiers. Each cavity contains of one gap and two tanks operating in push-pull mode and each tank will house 6 ring cores wound of modern magnetic nano-alloy ribbon. Meanwhile all ring cores were delivered and first results at low power and at high power will be presented. The construction of the new air cooling concept is now in the final stage.

RF Cavities

Different concepts of cavities and RF-power sources have been analysed to fulfil all operation modes especially the accumulation of Antiprotons [1] with desired gap-voltages. Ring cores wound of modern magnetic nano-alloy ribbons allow a very broadband operation and are well suited for a barrier-bucket (BB) operation. Both cavities will be driven by low noise solid state amplifiers to minimize ripples in the barrier bucket signals. The change from water to air-flow cooling spares vacuum impregnation of the ring cores and reduces the required RF-power to a moderate value.

Figure 1: One final ring core made of magnetic nano-alloy ribbon (Nanoperm of Magnetec; diameters: 500mm/200mm, height: 30mm).

The sizes of ring-cores (Fig. 1) have been optimized according to the fabrication process, suitable RF-losses and impedances, and also for an operation in the storage ring COSY for testing purposes (inner diameter limited by COSY beam tube size).The final layout will look like the following: Each cavity contains one gap and two tanks operating in push-pull mode. One tank will be filled with 6 ring cores. The combination of 2 parallel ring cores connected to one 1kW solid state amplifier gives the best matching condition, while the influence of the parasitic elements of the rings is reduced and the individual compensations of the rings' reactances lead to a higher bandwidth compared to the usual gap coupling.

Grouping the Ring Cores

Meanwhile all cores have been delivered. The differences between the rings are pretty low (+/-8% deviation of the impedances at h=1 and +/-10% at h=2) which demonstrates the consistent fabrication process. This allows an easy pairing of two parallel cores and a uniform distribution of the losses within one tank.

Table 1: Grouping of ring-cores within tank 1 of first cavity ($R_{(dc)}$: resistance between inner and outer diameter, $Z=R+jX$: RF impedance of one turn at the core; the last line shows the power factors).

Position	1	2	3	4	5	6	Gap
Core No.	2	22	28	3	4	9	
$R_{(dc)}$ / kΩ	2,2	3,8	4,4	6,2	7,5	8,7	
$R_{(h=2)}$ / Ω	104	102	106	109	114	112	
$X_{(h=2)}$ / Ω	56	56	57	56	65	59	
$R_{(h=2)}$ * 100Ω / $|Z_{(h=2)}|^2$	0,75	0,75	0,73	0,72	0,66	0,7	

The ring cores will firstly be grouped in pairs of nearly identical impedances at h=2 to 7. These six harmonics require 92% of the power of the ring cores driven by a 20%-barrier-bucket RF signal. Tab. 1 shows the data of three pairs (half a cavity) at h=2 as an example. Here we get nearly 50 Ohm per pair after compensation of its reactance by a series capacitor. The similar power factors provide a symmetric power loss of each pair within a few percent; that is necessary for the cooling concept. The reflected power is minimal at h=2 (around 1 MHz) and rises from 2% at h=4 to 12% at h=7, if the reactance has been compensated at h=2. Fig. 2 shows the input reflection of the first pair with and without compensation and demonstrates the good matching condition at h=2 and h=3. The spread between all pairs is nearly independent of the frequency and contributes only +/- 2% to the spread of acceleration tension.

The above numerical values are based on RF measurements at low level. A first experiment at 1 kW at 1 MHz reached an accelerating tension of 700 V at a single pair of ring cores. The low reflection coefficients lead to a B exponent of roughly 0.015 instead of the value of 0.08 taken in earlier calculations (power loss proportional to $(B/B_{crit})^{2.015}$). Therefore, the nonlinearity

at our highest RF tensions changes the impedances and power losses only by a few percent.
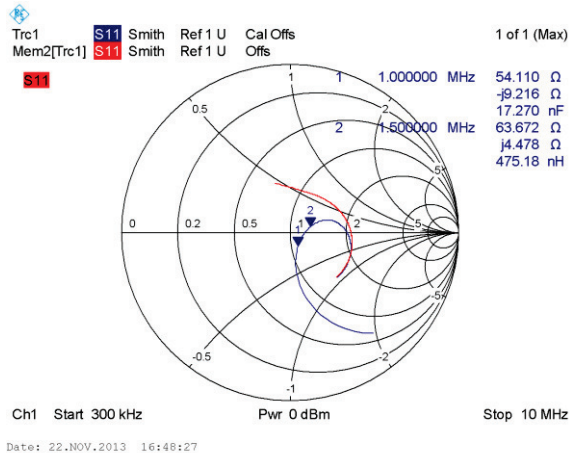

Figure 2: Input reflection coefficient of two parallel ring cores; red without compensation, blue with series capacitive compensation of each ring.

As the second grouping criterion, the dielectric strength of the interturn insulation of the ring cores has been used in form of the DC resistance between the inner and outer diameters. The calculated resistance of a ring core without interturn shorts amounts to 12 to 14 kΩ; the measured values range from 1.5 to 12 kΩ. The ledges of the ribbons are mostly unsymmetrically thicked and partially dislocate the interturn insulation. The resulting point shorts lower the DC resistance, but affect the RF impedance only by a few percent. Therefore, the ring cores of the largest DC resistance will be placed near the acceleration gaps (Tab. 1) where the largest RF electric fields appear.

New Cooling Concept

One critical design issue of the cavities is the air-flow cooling of the ring cores. The highest loss density occurs at the inner radius; 2/3 of the power will be dissipated from the inner radius to the mean radius. Significant heat conduction only takes place along the ribbon due to the interturn insolation. Thus the cooling system must guarantee an air flow that is almost homogenously distributed along the inner circumference; it requires at least 8 jet orifices at the inner circumference. Measurements at the old cooling disk containing radial slots of a width of 0.5 mm had shown that its air distribution system has too large and too much varying pressure drops. So, the air mainly flowed against only 4 points near the inner circumference. A redesigned cooling disk (Fig. 3) have been built containing 8 circumferential jet orifices fed by 8 separate air channels of large crossection. One side-channel blower will drive 3 of these new cooling disks belonging to one tank. The corresponding air flow power comes to about 300 W.

The temperatures of all ring cores will be individual surveyed and will deactivate the power amplifiers in case of exceeding 90°C of one ring core at least.
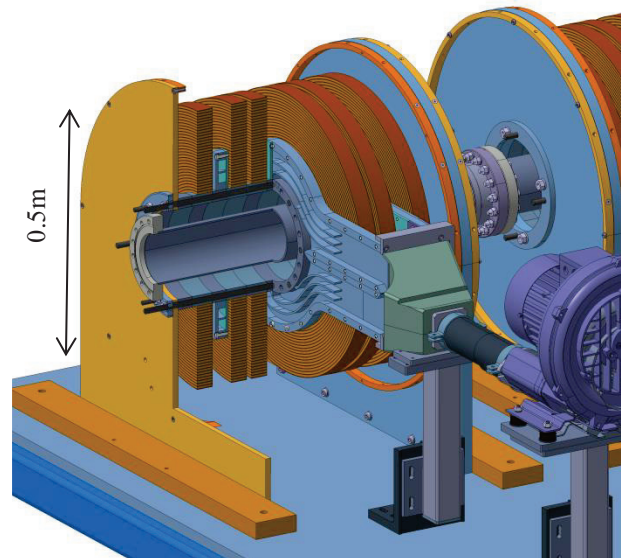

Figure 3: Sectional cut view of the redesigned new cavity.

High Power Operation

Two ring cores were installed into one test cavity tank and operated as BB cavity for the accumulation procedure (Fig. 4). Amplitudes of +/-500 V have immediately been reached with only one 500 W amplifier module. Here some ripples are tolerable because the 10%-BB-signals will be switched on only during the accumulation process where the BB will be used to create a sufficient gap for the next beam shot. At h=1 (500 kHz) in sinusoidal operation the output voltage was about +/-300 V limited by the reflected power. Thus the required voltages in all operation modes can easily be reached with the fully equipped cavities.
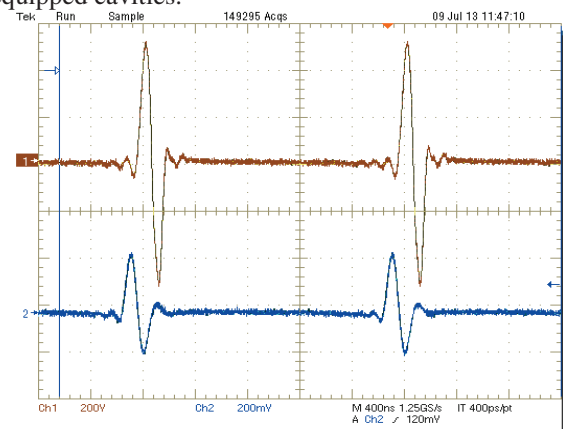

Figure 4: 10%-barrier-bucket operation of two ring cores; lower trace: predistorted drive signal, upper trace: BB signal of +/- 500V amplitudes.

Half-Sinus Barrier Bucket

Beside the normal single-sinus barrier bucket (BB) operation, a half-sinus barrier bucket signal was created and used together with the new 2 MV electron cooler at COSY. The same method [3] as for the single-sinus BB has been used to generate a pre-distorted signal for the

half-sinus BB operation, where the gap-voltage was translated in a Fourier series of 20 harmonics and the pre-distorted signal determined by a comparison of the coefficient.
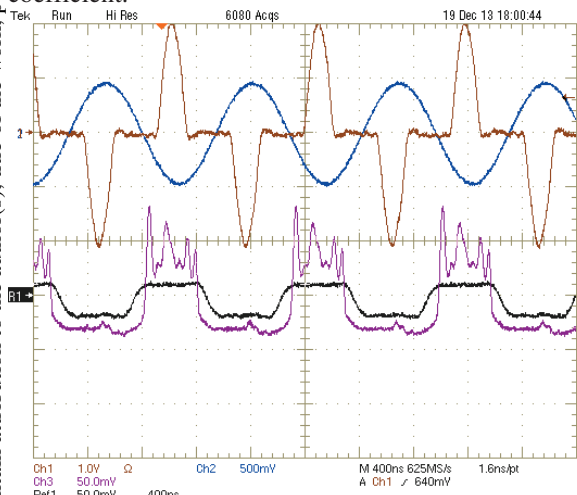

Figure 5: Half-sinus operation at COSY; upper trace: half-sinus signal compared to h=1 sinus signal, lower trace: phase monitor after 5s of cooling (black curve and after 50s of cooling (magenta).

The half-sinus signal divides the longitudinal phase space of COSY into two areas, one stabile area and one unstable area where the particles are moved out of the bucket area. The electron cooler cools now all particles into the stable area. Small ripples between the barriers in the stable area caused local minima. Once cooled into the minima particles will be trapped and produce the ripples in the distribution shown in Fig. 5 lower magenta curve. The half-sinus BB operation together with the new 2 MeV E-cooler has been simulated.
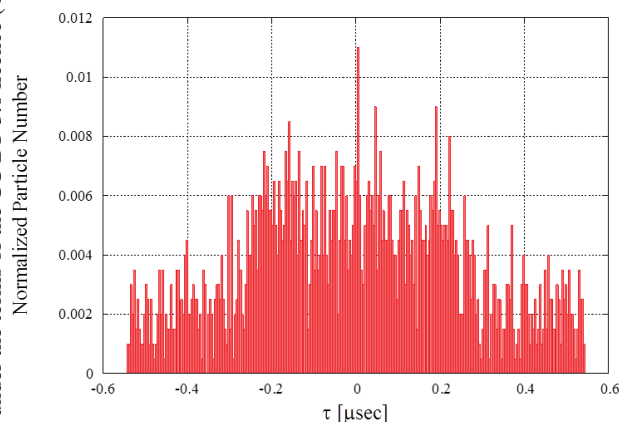

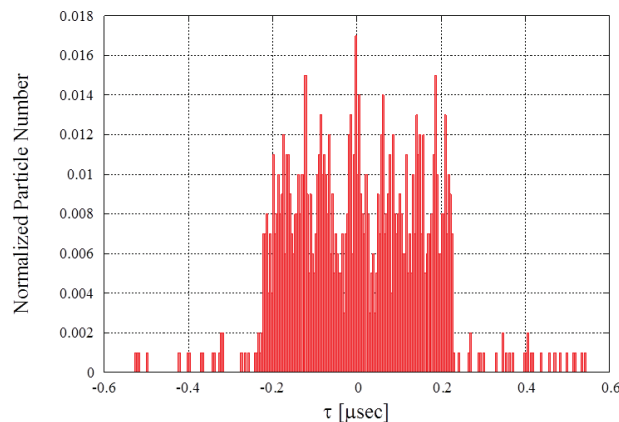Figure 6a: Simulated particle distribution after 5s of electron cooling.

Figure 6b: Simulated particle distribution after 40s of electron cooling.

The corresponding results [4] are shown in Fig. 6a/b and do well agree with the measurements at COSY. So, this principle can be used in the HESR to create a loss free gap in the pbar beam at low energies for possible future upgrades of the pbar chain [5].

ACKNOWLEDGMENT

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