THE HESR RF-SYSTEM AND TESTS IN COSY

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Abstract

Two RF cavities will be installed in the High-Energy Storage Ring (HESR) of the future International Facility for Antiproton and Ion Research (FAIR) in Darmstadt. One "large" cavity will be used for beam acceleration, deceleration and for bunch rotation. Additionally a barrier bucket (BB) with h=1..5 will be formed by this "large" cavity to combine the decelerated bunch with a new injected RESR bunch in the high luminosity mode (HL). During the experiment a "small" cavity will provide a low noise barrier-bucket signal. Both prototype cavities are manufactured and first RF-measurements were carried out at COSY. The recent results are presented here.

ACCELERATING CAVITY

A typical RF operation scheme and the resulting beam parameters for the high-luminosity mode (HL), N= 10^{11} at highest HESR energy, are summarized in table 1.

Table 1: RF operation in HL-mode

	Bunch length	RMS energy, momentum spread
1. step: 10^{11} particles from RESR, 10^4 sec		
Injection of $\mathbf{N=10^{11}}$ particles, 3 GeV	150m	σ_E= 1.94 MeV, σ_p/p =5.1*10^{-4}
Acceleration to 14 GeV. Bunch rotation (BR) to get DC beam for cooling	575m	σ_E= 0.48 MeV, σ_p/p =5.1*10^{-4}
At end of exp.: cooling of remaining $\mathbf{6*10^{10}}$ particles, no target, to reduce energy spread	575m	σ_E=0.65 MeV, σ_p/p =0.45*10^{-4}
2. step: deceleration to 3 GeV, refill		
3 GeV: $\mathbf{6*10^{10}}$ particles, after BR	150m	σ_E= 2.6 MeV, σ_p/p =6.8*10^{-4}
refill: $\mathbf{4*10^{10}}$ particles from RESR ,4*10^3 sec	150m	σ_E= 1.37 MeV, σ_p/p =3.6*10^{-4}
Combine both bunches: Debunching and BB to get one bunch, $\mathbf{N=10^{11}}$	575m	σ_E ~ 1.37 MeV, σ_p/p ~3.6*10^{-4}
N=10^{11}**,** bunch formation inside HESR acceptance	300m	σ_E ~2.74 MeV, σ_p/p ~7.2* 10^{-4}
3. step: acceleration to 14 GeV		
10^{11} particles, after BR	575m	σ_E ~1.37 MeV, σ_p/p ~0.95*10^{-4}
14 GeV, ending exp. & add. cooling, $\mathbf{N=6*10^{10}}$	575m	σ_E= 0.65 MeV, σ_p/p =0.45*10^{-4}
4. step: go back to step 2		

Values are based on no particle loss and conserved phase space area during acceleration, de-acceleration and RF bunch manipulation.

The accelerating cavity of the HESR [1] will be operated as dual harmonic cavity with voltages up to 5kV [2]. The basic parameters of this cavity are summarized in table 2. The cavity consists of two tanks with a total length of about 80 cm including the acceleration gap. The outer diameter is slightly less than 60 cm. Each tank is loaded with 6 cores of FineMet 3M® [3].

Table 2: basic cavity parameters

HESR rev.frequencies	440 kHz – 520 kHz
Frequency-range	1..10 harmonics (0.4 - 5 MHz)
Gap voltage	100 < 5000V peak
No of gaps	1
No of tanks	2
Mode of operation	cw
Cooling	Water-cooled
Material	FineMet 3M

The impedances of all FineMet cores have been measured individually. This allowed a grouping into the two cavity tanks, showing similar impedances both for the real and the imaginary part (Fig. 1).

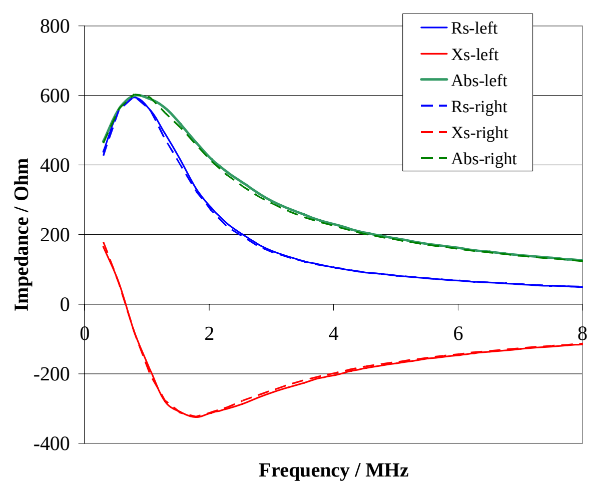

Figure 1: Impedances of both cavity-tanks after arranging the FineMet cores and assembling the cavity with a dummy gap.

The cavity was installed on top of the former COSY [4] tube amplifier. After some modification concerning the coupling this amplifier is suitable to fulfil all HESR relevant RF-requirements.

First RF-measurements have been carried out, reaching a gap-voltage of 4kV peak-peak at each cavity tank at 1MHz over several hours of operation. Further tests

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including the dual harmonic and barrier bucket operation in the required frequency range will be done next.

Figure 2: Accelerating cavity installed on top of the former COSY tube amplifier.

BARRIER BUCKET CAVITY

A broadband barrier bucket cavity in the HESR is not only used to improve the antiproton lifetime by building a 10%-20% time gap but also together with the stochastic cooling [5] to compensate the mean energy loss provoked by the pellet target. Starting from the broadband COSY cavity [6] the design, production and assembly of the barrier bucket cavity has finished using one COSY tank with minor changes.

Figure 3: The barrier bucket cavity with its asymmetric layout is installed in one arc of COSY. In this figure the shielding of the gap is dismounted to make it visible.

The asymmetric layout of the cavity with one gap results in a very compact design (length of cavity without gap: 28cm). The length from flange to flange including the gap is in the order of 50cm. The basic parameters of the cavity are summarized in table 3. After measuring the impedance of the cavity with and without cooling water the cavity was installed in the COSY ring (fig. 3). The influence of the cooling water is rather high, thus detailed calculation will be done to decide whether water-cooling is really needed or a forced airflow cooling would be sufficient. The Cooler Synchrotron COSY [4] allows many HESR relevant experiments, such as the operation of the prototype barrier bucket cavity together with a pellet target and a stochastic cooling system [7].

Table 3: Basic parameters of the barrier bucket cavity

Frequency-range	1..20 harmonics (0.4 - 10 MHz)
Gap voltage	10<600V
Mode of operation	cw
Cooling	Water-cooled, but design work started to built a forced airflow solution
Material	VitroPerm 500F

Signal synthesis to optimize barrier bucket operation

An arbitrary waveform generator (AWG) was used to generate a barrier bucket signal, which was applied to a solid-state amplifier driving directly the barrier bucket cavity. After measuring the corresponding gap-voltage we calculate the Fourier series of the transfer-function and can determine a pre-distorted barrier bucket signal, which gives the desired sinusoidal gap-voltage (Fig. 4).

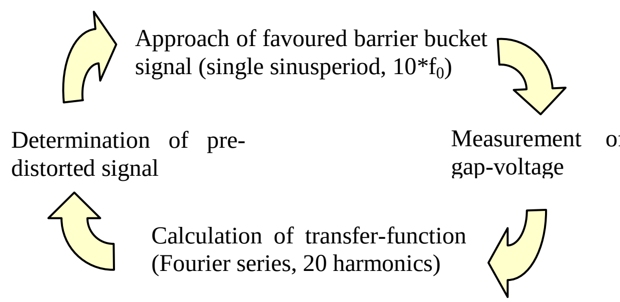

Figure 4: Scheme of signal synthesis procedure

Operation of the BB cavity at COSY

The revolution frequency of COSY at most experiments differs compared to the HESR requirements by nearly a factor of three. At this higher frequency the effective signal generation for a barrier bucket is not only limited by the cavity but also by the used arbitrary-waveform generator. All further tests were carried out using a single sinusoidal barrier bucket signal with a frequency of roughly three times higher than the particle revolution-frequency triggered by the h=1 RF system. A DC-pulse was added to the barrier bucket signal to minimize the signal overshot at the gap. During a WASA [8] beamtime the barrier bucket operation was tested together with stochastic cooling and a thick pellet target. Fig. 5 shows the barrier bucket voltage at the gap limited by the available RF power (upper blue curve) and the phase monitor proportional to the distribution of the particles. Curve a) (black) represents the nearly rectangular distribution at the beginning of the cycle formed by the barrier bucket. Without cooling and without target this shape remains constant over the whole cycle length of 160sec (curve b) red). The voltage in the region between the sinusoidal barrier signals is not identically zero; there is a ripple of about 3%, which forms a minimum in the potential. The stochastic cooling collects the particles to this minimum, so the distribution stays no longer constant (curve c) blue). The thick pellet target counteracts the stochastic cooling which is directly visible (curve d)) in a lower asymmetry of the bunch shape. The experiments thus have shown that a flat BB potential is absolutely necessary for a good cooling efficiency and a flat beam distribution.

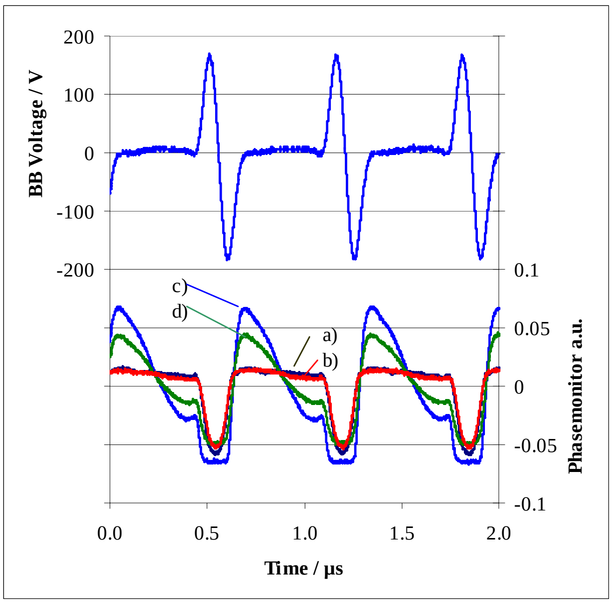

Figure 5: First barrier bucket operation together with stochastic cooling at COSY.

The influence of barrier bucket and stochastic cooling is presented in Fig. 6, where the longitudinal spectrum measured at the 1000th harmonic is plotted. Curve a) represents the momentum spread at the beginning of the cycle. Without stochastic cooling and barrier bucket, the energy loss and the longitudinal heating by the pellet target is clearly visible over the cycle length of 160sec (curve b)). The momentum in COSY was 2.6GeV/c. At this working point the machine operates above gamma-transition, thus energy losses result in a higher revolution frequency. Even with the relatively low numbers of particles $N=8*10^8$ the stochastic cooling (band 2: 1.8-3GHz) alone is not able to compensate for the whole energy loss by the target (curve c)). Curve d) shows the situation where the mean energy loss is compensated by the barrier bucket system, and the momentum spread is significantly reduced by the stochastic cooling. Nevertheless some particles were lost due to the barrier height of +-175V limited by the available RF-power.

Taking into account the frequency shift during the whole cycle we calculated a target thickness of $N_T \approx 3.6*10^{15}$ atoms/cm², which corresponds to the expected PANDA target.

The mean energy loss can also be compensated with the normal RF-cavity. Since the voltage is much larger than that of the BB all particles were captured and no losses occurred. However due to the large bunching factor stochastic momentum cooling was rather poor, i.e. no cooling effect was visible.

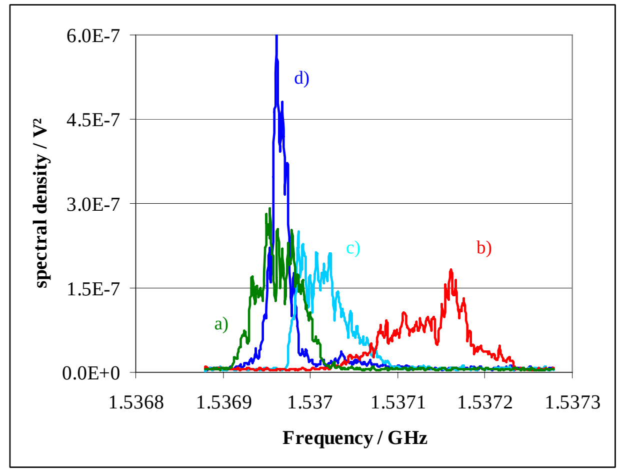

Figure 6: Schottky spectra of COSY beam measured at the 1000th harmonic: a) starting distribution, b) final distribution after 160sec only pellet-target, c) final distribution with longitudinal stochastic cooling and d) final distribution with cooling and barrier bucket.

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