RF SYSTEMS FOR RHIC[*]

J.Rose, J.Brodowski, R.Connolly, D.P.Deng, S.Kwiatkowski, W.Pirkl, A.Ratti
Brookhaven National Laboratory, Upton, N.Y. 11973

Abstract

The RHIC rf systems must capture the injected beam, accelerate it through transition to top energy, shorten the bunches prior to rebucketing, and store the beam for 10 hours in the presence of strong intra-beam scattering. These different functions are met by three independent systems. An accelerating system at 26.7 Mhz (h=342), a storage system at 196.1 MHz (h=2508), and a wideband system for the damping of injection errors.

I. RING PARAMETERS

The Relativistic Heavy Ion Collider (RHIC) under construction at Brookhaven National Laboratories consists of two rings with a 3833.852 meter circumference, with six intersection points for colliding beam experiments. The collider is required to accelerate any ion species from protons to gold. With the exception of protons, all ions must cross transition.

The baseline design calls for 57 bunches to be injected from the Alternating Gradient Synchrotron (AGS) with an upgrade capability to 114. Because of the variety of ions the collider must accelerate the beam parameters are best described in terms of protons and gold, which are listed in table I, with other ions falling between these extremes.

	P (inj)	P (top)	Au (inj)	Au (top)
Energy (γ)	31.2	268.4	12.6	108.4
Bunch length (ns)	6.5	4	13.5	7.5
Synch. freq. (Hz)	45	25	90	27
Bunch area (eV/u)	0.3	0.3	0.2	0.4
Emittance norm, 95% (πmm-mrad)	20	20	10	15
Number ions/bunch	10^{11}	10^{11}	10^{9}	10^{9}

Table I RHIC beam parameters

II. RF CYCLE

A. Injection

Individual bunches from AGS are injected into any preselected matched bucket in RHIC, to allow complete freedom in how the ring is filled. Issues at injection include emittance growth due to intrabeam scattering for gold (growth rate of 6 min.). Since protons are injected above, but close to transition the nominal matching voltage is 19 kV, whereas the beam induced voltage is 12 kV. In order to avoid beam control problems associated with the large transients a bunch rotation in AGS is proposed to increase the momentum spread, and hence the matching voltage. A decrease in bunch length of 1.8 would lead to a factor of 10 increase in rf voltage, thus relieving the beam loading. Momentum errors of the order 10^{-4} are expected and if not corrected would lead to emittance growth of 30%. A wideband damping system with a kick voltage of 1000 V/turn will reduce emittance growth to 10%.

B. Acceleration

Gold ions are accelerated from γ=12.6 to γ=108.4, requiring a 0.5% tuning range of the accelerating system. The superconducting magnets take about 74 s to ramp up to top energy, which relates to a maximum tuning rate of 18 kHz/s. The rf voltage ramp will be varied to prevent the synchrotron frequency from dwelling near power line harmonics. Especially dangerous is the region of $30\text{Hz}<f_s<40\text{Hz}$, which must be passed through in less than 4 seconds.

C. Transition

The slow acceleration rate of a superconducting machine produces a long (100 ms) non-adiabatic time which can result in both emittance growth and beam loss. Beam is lost from chromatic non-linear effects and microwave instabilities due to bunch shape mis-match during transition crossing. A γ_T jump of 0.8 units in 60 ms is proposed to minimize these effects. The accelerating rf system must be able to switch phase (π-ϕ_s) in this time and the beam induced voltage in the storage system kept below 10kV/turn to minimize emittance blowup.

[*] Work performed under the auspices of the Department of Energy

D. Rebucketing

Rebucketing is the process of moving the bunch from the 26.7 MHz system to the 196.1 MHz system. Because the bucket length in the 196.1 MHz system is 5ns, in order to have a 20% safety margin the incoming bunches must be 4ns long. The bunches are nominally 6 ns long in the 300 kV bucket, to adiabatically shorten them with the accelerating cavities would require a prohibitive 1.5 MV. A bunch rotation at top energy is therefore proposed. At top energy the bunch will be shifted to the unstable fixed point where it debunches in a fraction of a synchrotron period, and the bunch shifted back to the stable fixed point. The bunch, now being mismatched, starts to rotate in phase space. In 3/8 of a synchrotron period has reached its minimum length position and the storage system is turned on. The details of this process are described in these proceedings[1].

E. Storage

The storage rf system provides longitudinal focusing to maintain short bunches for the physics program in the presence of large intra-beam scattering forces.

III. ACCELERATING SYSTEM

The accelerating system consists of two 26.7 MHz cavities per ring to provide the necessary 600 kV per turn. The accelerating cavity is a capacitively loaded coaxial quarter wave structure roughly 2m long and 0.84 m in diameter. It is fabricated from copper plated carbon steel with all metal seals throughout. A complete description of the cavity is given in these proceedings[2]. It is driven by an EIMAC 4CW150000 tetrode which is mounted directly to the cavity and loop-coupled. The configuration is shown in figure 1.

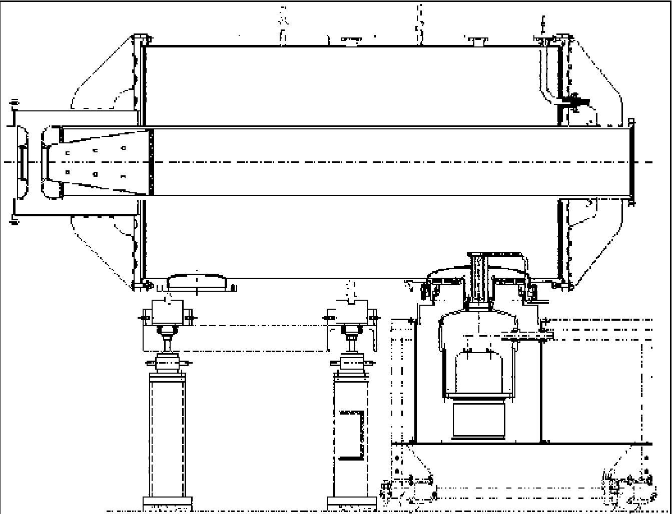

Figure 1 26.7 MHz accelerating cavity

A 1 kW solid state driver amplifier has been developed which will be located within the tunnel to minimize delay. This configuration allows greater than 45 dB of fast rf feedback to be closed around the cavity for impedance reduction. Since this loop is closed around the AVC and tuning loops the tolerances on these loops can be relaxed by either the feedback gain or the limits of the power amplifier, whichever is reached first . A mechanical tuner[3] operates by moving one of the gap electrodes to change the capacitance and achieves a range of 300 kHz. The 18 kHz/s tuning rate dictated by the superconducting magnet ramp translates into a bandwidth requirement of less than 20 Hz.

IV. STORAGE SYSTEM

The storage system consists of ten 196.1 MHz ten re-entrant cavities operating in the TM_{010} mode. These are arranged with four cavities common to both beams in an interaction region, and three additional cavities per ring in the separated arc region to maintain control of the individual beams. This gives seven cavities per beam, each capable of 1 MV. The requirement of 6 MV per ring can be met with any single cavity disabled. Originally a 160 MHz system was planned but it happened that CERN was introducing superconducting cavities in the SPS ring and was decommissioning part of the 200 MHz "SWC" system. A feasibility study determined that these cavities could be tuned to 196.1 MHz and adapted for use in RHIC. Each CERN cavity is equipped with a close-coupled power tetrode, two HOM supressors, a pneumatically controlled damping loop to reduce the impedance of the fundamental and a DC servo driven tuner, with 400 kHz operating range. A complete system description may be found in the reference[4]. The cavity with the power amplifier, damping loop, HOM suppressors and tuner is shown in figure 2.

In the installation at CERN groups of eight cavities share a common driver and power supply. For operation at RHIC individual power supplies are required to allow operations in the event of a power supply crowbar or failure. Individual driver amplifiers are necessary to be able to implement fast rf feedback around the cavities to reduce the impedance of the fundamental and hence the transient beam loading effects. A solid state 4 kW commercial fm broadcast amplifier is being purchased for testing. These drivers must be located in the ring to minimize the delay in the feedback loop, and must be shielded from the radiation environment. The cavities are tuned by squeezing the cavities with a large lead-screw crusher and increasing the capacitance of the gap to lower the frequency. The HOM suppressors are folded coaxial quarter wave notch filters which likewise have to be tuned to the new frequency. The power tetrode is matched to the 16 ohms of the coupling loop through a series of quarter wave transmission lines which again have to be re-tuned to 196.1 MHz. The damping loop is

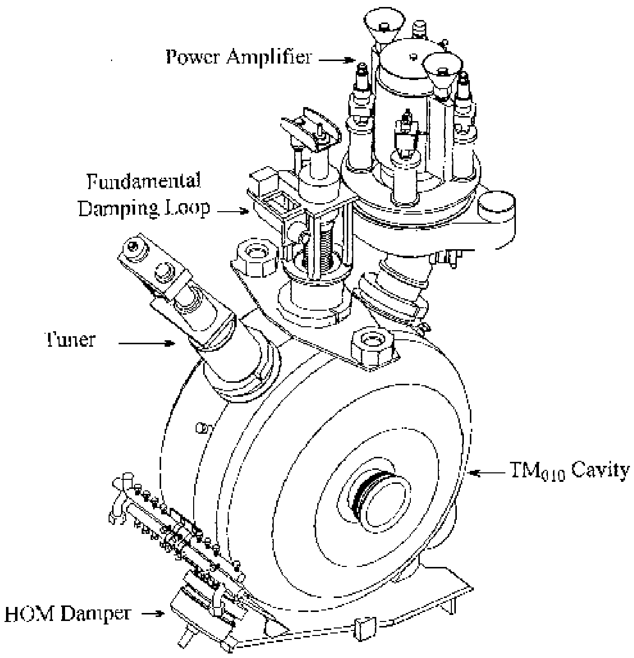

Figure 2 Storage cavity (CERN SPS "SWC" cavity)

still required for RHIC to de-Q the fundamental 8.9 MΩ impedance to reduce the beam induced voltage at transition crossing. These also require tuning to operate at 196.1 MHz.

V. WIDEBAND SYSTEM

There is one wideband system per ring to act as a longitudinal damper to damp out momentum errors at injection. Because RHIC operates with bunch to bucket injection this system must act on individual bunches. This requires a bandwidth of at least +/- $57f_0$ for the case of 114 bunches, where f_0 is the bunch rotation frequency.

Acknowledgements

The authors wish to thank J.M.Brennan for many helpful discussions of the system requirements. M. Harrison, S.Peggs and the RHIC accelerator physics group made significant contributions to Reference (1) which served as the basis of this paper.

References

1) RHIC RF and AP groups, "Conceptual Design of the RHIC rf System" RHIC RF-22 technote.
2) J.Rose et al "Design of the 26.7 MHz RHIC Cavity" these proceedings
3) J.Rose et al "Design and Performance of a Prototype Tuner for RHIC" these proceedings
4) P.E.Faugeras "The New rf System for Lepton Acceleration in the CERN SPS" Particle Accelerator Proceedings, 1987